

The AMSAT[®] Journal

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*K HI hier ist AO13, der intern, Satellit zur Foerderung von Wiss
enschaft, Amateurfunk und vor allem internationaler Freundschaft
und Zusammenarbeit.*

** DANKE KARL **

Figure 1. OSCAR-13's first beacon message: *Hi, this is AO13, the international spacecraft to support science/education, amateur space communication and above all international friendship.*

*M QST de AO-13 *** BIRTH ANNOUNCEMENT *** 1996 Nov 20 0240 EST*

*My child, P3D, began "thinking" today when its IHU was activa-
ted. I'm glad I lived long enough to learn of this wonderful
event. I wish P3D a long, functional life. Do not grieve for
me when I'm gone. I'm only metal, plastic, & sand. My "life"
came from enriching the lives of those who built, commanded &
utilized me, and it's been a good "life". Danke Karl, et al. No
regrets. The baton will soon be passed. AO-13 signing off...*

Figure 6. This final telemetry message block appeared on OSCAR-13 a couple of days before the spacecraft failed.

OSCAR-13's Life and Death

James Miller G3RUH, (g3ruh@amsat.org)

AMSAT OSCAR-13 (AO-13) was launched from Kourou, French Guiana on 1988 June 15 on the first test flight (V-22) of the Ariane 4 rocket, along with Panamsat and Meteosat P2. Eight and a half years later AO-13 re-entered and burned up on 1996 December 5.

Lift-off was 1119:01 UTC; at 1239:04 Phase 3C became OSCAR-13 when it was ejected from the carrying structure, and at 1403:38 UTC sprang to life with the activation of its 145 MHz telemetry beacon. ZL1AOX reported the satellite to be in perfect health.

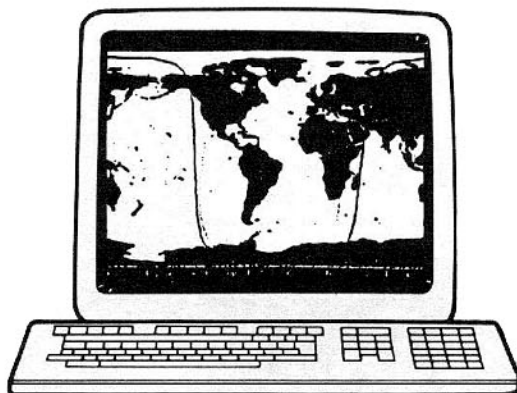
[continued on page 4]

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giving freely of their talents, time, and efforts to produce *The AMSAT
Journal*.

Apogee View

For this issue, I am turning over this space to our Editor, Russ Tillman, KC5JVB. I believe that he has something important to say regarding the future course of our organization. Bill Tynan, W3XO

Board of Directors Nominations Due Soon

The Bylaws of the Radio Amateur Satellite Corporation (AMSAT) require that we hold annual elections to elect members of our seven-member Board of Directors. They further stipulate that names of the candidates who have been nominated must be sent to all current members by June 15, and that the results of the election be announced by September 15. The Bylaws also set forth the manner in which nominations for the AMSAT Board are made. Nominations may come from AMSAT Affiliated Societies. These are clubs or other types of societies which have officially joined the organization. Alternatively, any five current AMSAT members may nominate one or more persons to serve on the Board. In order to achieve this mandated schedule nominations and the candidates' biographical statements must be at AMSAT HQ by June 1. Then, by the 15th, Martha must print and mail over *seven-thousand* copies of the ballot plus biographical information. So, if your club is an Affiliated Society of AMSAT it can make nominations. Or, if you wish to get together with four other members and nominate someone, please do so soon.

An announcement of this year's Board election appears on Page 22 of this issue. As noted in the announcement, the Bylaws call for the Directors to serve for two years and that four Board members are elected in odd-numbered years and three in even-numbered years. Also provided for is an Alternate Director to serve for a period of one year, until the following year's election. This year the terms of Dick Daniels W4PUJ, Junior de Castro PY2BJO, Bob Myers W1XT, and Bill Tynan W3XO expire.

I want to emphasize how important the election of qualified Board of Directors members is to our organization. The Board must set AMSAT policies, control its finances and chart its current and future course. Being a member of the AMSAT Board entails work. Even though it may be a honor, it must be much more. The Board holds at least one

meeting per year, usually following the Annual Meeting and Space Symposium. That usually means skipping any Sunday activities and staying over into Monday. Sometimes, when the need arises, we hold a second meeting, usually in the spring in the Washington, DC area. It is very important that *all* Board members be present for these meetings. AMSAT Board meetings can be long and are often arduous. For example, in June 1996 the Board met at the Office in Silver Spring, MD. The meeting began at 9:00 AM and finally concluded at 9:30 PM that evening. There were no breaks except to order lunch, which was eaten while continuing the meeting. It was just plain *hard work*, but they accomplished the main reason for the meeting; finalizing and approving our recommendations for the Future of the Amateur Service Committee (FASC) established by the IARU to help in its WRC-99 planning. To get an appreciation for the type of issues with which this and other AMSAT Board meetings must deal, carefully study the minutes of the various meetings that have appeared in past issues of *The AMSAT Journal* (see Sep/Oct 1996 and Jan/Feb 1997).

As AMSAT members, it is vital we be familiar with the kinds of issues with which the AMSAT Board members must deal, and realize that all who are elected must be present at scheduled meetings in order to properly represent you. They must have a background in Amateur Radio and amateur satellites as well as a knowledge of finance and sometimes even law. It is often helpful that they have had experience in the design and construction of spacecraft and the difficulties connected with obtaining launches.

AMSAT is now a seven-thousand member organization with assets exceeding *one-half million dollars*. We are just completing a project in which we have raised, with the help of ARRL, well over *one million dollars*. We need well qualified, dedicated people on our Board to make certain that AMSAT is around in the years to come to continue to provide the kinds of service to Amateur Radio that it has for the past 28 years.

It's up to us, the membership, to nominate and elect people who can do their part in assuring the continued viability and leadership of the Radio Amateur Satellite Corporation. ■

[OSCAR 13's Life and Death, continued from page 1] Its first message blocks contained a welcome in German (Figure 1), English, Spanish, Portuguese and French.

OSCAR-13 was launched into a highly elliptical equatorial orbit, a *Geostationary Transfer Orbit*, with a perigee height of 240 km spinning at five rpm. Over the next seven days it was spun up to 26 rpm, and re-oriented to point the motor along-track such that apogee velocity could be increased by 150 m/s. This increased perigee height to 1100 km, and freed the satellite from buffeting and atmospheric drag.

During the next two weeks it was spun up to 60 rpm, and oriented *upwards* so that a burn at apogee would increase inclination to 58°, and perigee height to 2500 km. The delta-V was 1314 m/s.

Two weeks later, 1988 July 22 at 1500 UTC the Mode-B transponder was switched on for general use, and the rest is history. (It was in fact discretely tested for a few minutes the previous day).

AO-13 Performance

With its apogee distance of approximately 40,000 km, OSCAR-13 gave global VHF/UHF/SHF radio coverage to thousands of Amateur Radio operators. Apogee was initially over the equator, drifting maximally Northwards for the start of 1992, back to the equator again by 1995, and ending around 45° South two years later. For the most part, its performance was outstanding, and gave great pleasure to many people. Indeed, for some it became a way of life.

It is instructive to review the factors which made OSCAR-13 so remarkable. We should look at both successes and failures. A spacecraft consists of a Bus which carries Payloads.

Payloads

Payload	Status	Comments
2.4 GHz TX	OK	
435 MHz TX	OK	Failed after 5 years
145 MHz TX	OK	
1.3 GHz RX	OK	Low sensitivity
435 MHz RX	OK	
RUDAK	—	Never worked

Let's take a detailed look at the payload successes and failures.

Payload Failures

OSCAR-13 carried a packet radio digital regenerator experiment called RUDAK. The engineering model was tested to great satisfaction from a water tower near Munich, and pre-launch in AO-13. But in space, to universal disappointment, it never worked, nor could it be persuaded, via diagnostic probing, to reveal any reason for not working. Intensive testing was tried twice, soon after launch, and again a year later, then abandoned.

The Mode-L 1269 MHz receiver system sensitivity was 10x too low. A requirement for at least 5 kw EIRP deterred most operators. Had the sensitivity been correct, 10 watts to a long Yagi would have been ample, and Mode-L might have been as popular as Mode-B, maybe more so, because the 70 cm downlink is such a quiet band. No explanation was found.

The 435 MHz transmitter failed abruptly on 1993 May 19. So that was the end of Mode-L anyway, and the best telemetry beacon. The transmitter used to run at typically 41C, which may point to the cause of its failure. However, the L-band 1269 MHz RX remained to the end, used for command purposes in conjunction with the S-band downlink.

Payload Successes

The most popular mode for over a decade, the Mode-B 145 MHz transmitter was on virtually continuously, some 60,000 hours, interrupted only by typically a couple of hours at apogee for Mode L and/or Mode-S with their more directional antennas. This was a great achievement for the electronics, particularly the transmitter. The design is based on the HELAPS principle where the output signal is decomposed into its amplitude and phase components. The phase information is processed by a class D power amplifier, and the amplitude is modulated back onto the result. This technique results in a very power efficient, and therefore cool-running, wideband amplifier. The HELAPS concept was pioneered by AMSAT.

The S-band transponder also turned out to be a great success. It was built essentially as a technology demonstration, and as such had known limitations, low power and hard limiting. Initially perceived as a techie's toy, a bit of eloquent persuasion [1] showed this

not to be the case. Large numbers of users had a go, and are now ready for what promises to be the workhorse mode for Phase 3D. Bill McCaa K0RZ certainly deserves thanks for his farsightedness over 12 years ago, and for nursing the S-band transponder project to fruition.

The Bus

Turning now to the Bus. That's the metal-work, motors, flight computer, batteries and so on that are needed to support the payloads.

Successes Failures

Thermal Design	NONE
Motor System	NONE
Battery System	NONE
Magnetorquing System	NONE
Navigation System	NONE
Computer System & IPS	NONE
Command & Telemetry	NONE

Bus Successes

The AO-13 bus has been extraordinarily successful. Virtually nothing has broken, and what has was trivial. It's an outstanding achievement, even more so when you realise that AO-13's pedigree dates from 1979 and Phase 3A. Let me touch briefly on a few of the systems we took for granted.

Thermal Design

AO-13's thermal design worked perfectly. The satellite enjoyed a benign shirt-sleeve internal environment whatever the Sun's position. There were no structural hot spots. During eclipses the solar panels reached -40C, but the internals rarely fell below zero. It's no mean feat to achieve good thermal balance, which is based solely on juggling the radiation characteristics of the various exposed parts of the structure, by choosing reflective or absorbing coatings.

Motor System

The bi-propellant hydrazine and nitrous oxide 400 Newton motor system behaved flawlessly during the two post launch burns. Another outstanding success, and a fine tribute to its highly skilled specialist engineers.

Battery System

AO-13 carried two batteries; the main and the auxiliary or back-up. The main battery was still going very strong, and could support the

spacecraft through a 2-hour eclipse. There was a little concern in 1993 when it was thought to be ailing; it just wouldn't hold charge. Then it was realized that it hadn't actually got any charge to hold, because the regulator control set points had not been altered since launch to reflect aging of the solar panels. Aging alters a panel's characteristic voltage-current curve quite a lot. Once these control points were altered, a matter of a fraction of a volt, the main battery came back as strong as ever.

The auxiliary battery, which was normally fully discharged, was accidentally charged in 1991. On 1996 May 26 the auxiliary was deliberately recharged for 24 hours to see what would happen. It stayed charged for only seven days, and the delivered capacity appeared to be down to 0.1 A-H. So on 1996 June 19 it was recharged again, this time for a week. Its voltage held up until the end of September. A final recharge was given on 1996 November 16, *just in case* it was needed during the final weeks. However it was never actually used to power the spacecraft because once invoked, switching back to the main battery would have caused a power surge which might have proved fatal.

There were two Battery Charge Regulators (BCR) on board, both of which were exercised regularly, one at a time. These are essentially 50 watt switched mode power supplies taking some 30-35 volts from the panels and delivering 14.5 volts to the battery with a very high conversion efficiency. Both performed perfectly. Another outstanding design.

Magnetorquing System

OSCAR-13 needed to be re-oriented from time to time to ensure sufficient illumination of the solar panels. This is accomplished by the magnetorquing coils. These electromagnets form the rotor of an electric motor. The stator is formed by the Earth's magnetic field, and commutation of the coil current is performed by the on-board computer. In this way the satellite's spin rate and spin axis direction can be changed as required. It's a delightfully simple concept, and another outstanding success.

Navigation System

Attitude determination was performed by on board measurement sensors, and by on-the-ground data processing software. Measure-

ments were made by a Sun sensor and an Earth sensor. Both instruments worked fairly well. In recent years we had to use their data with great care in that they were prone to give unexpected results which needed to be explained, and that wasted time. There was some evidence of clouding of their cover glass, and certainly of changed photodiode sensitivities. In fact the navigation sensors were the most delicate part of the bus design, and uncertainties in their operation and the need to interpret their data with considerable skill and judgement resulted in perhaps the largest expenditure of ground station time.

Computer System, IPS, Command, and Telemetry

Finally, the spacecraft's many functions were coordinated by the on-board computer system called IHU. This comprised the CPU, memory, data multiplexer, command decoder, telemetry encoder and of course the flight software itself. These things were the *heart* of the spacecraft.

The flight computer proved fantastically reliable. Based on the 1802 Cosmac processor, executing just 200,000 instructions/sec it didn't really miss a beat since launch. There have been so-called crashes, where the program stopped. Two of these were definitely known to be operator error, such as sending the Reset command by mistake, and the others occurred at times of great testing activity and are virtually certain also to have been operator error. No crash can definitely be linked with radiation hits. And more remarkably, no crash can be attributable to faulty software. I think we had here an example of

that very rare object, a bug-free Operating System.

In any event, ignoring two stoppages due to simple operator error, the flight software ran faultlessly for at least seven years. Over its whole life the spacecraft was sent 4628 commands, an average of 1.5 per day (Figure 2).

In May 1994 the computer memory error detection and correction circuits started flagging errors at a rapid rate, initially 3, later about 12 per orbit. Command stations could not discern whether these represented real memory corruptions, or a minor malfunction of the EDAC circuitry itself. Either way, the flight software didn't crash, so it was a benign fault, and probably due to a partial logic failure.

Command and telemetry systems proved robust and worked extremely well. The formats carry over unchanged to the Phase 3D satellite.

The OSCAR-13 Flight Computer system is an engineering tour de force which deserves unqualified praise. And at its heart is the operating system, written in a Forth-like language called IPS, which was devised by Karl Meinzer DJ4ZC in 1977-78. Its exquisite design is in fact one of Karl's greatest achievements, something that has certainly never been properly recognised.

That the same flight computer, IPS language, command and telemetry systems are built into the Phase 3D satellite presently under construction, is greatly reassuring. [2]

Load	From	To	Total Commands	Life Days	Rate Comms/Day	Notes
1	1988 Jun 15	1989 Oct 19	1173	481	2.44	st
2	1989 Oct 09	1989 Oct 28	390	19	20.53	rt
3	1989 Oct 28	1989 Dec 10	224	43	5.21	rt
4	1989 Dec 10	1991 May 13	759	519	1.46	po
5	1991 May 13	1992 Jan 29	248	261	0.95	rs
6	1992 Jan 29	1996 Nov 24	1834	1761	1.04	—
Total			4628	3084	1.50	

Notes:
 st Soon after Mode-S control routine testing.
 rt Just after intensive RUDAK testing.
 po Investigation of navigation problem induced a *poke* with its address and data transposed.
 rs Reset command inadvertently sent.
 — S/C failed from overheating at perigee.

Figure 2. OSCAR-13 command history from launch to failure. Over its life the spacecraft was sent 4628 commands, an average of 1.5 per day.

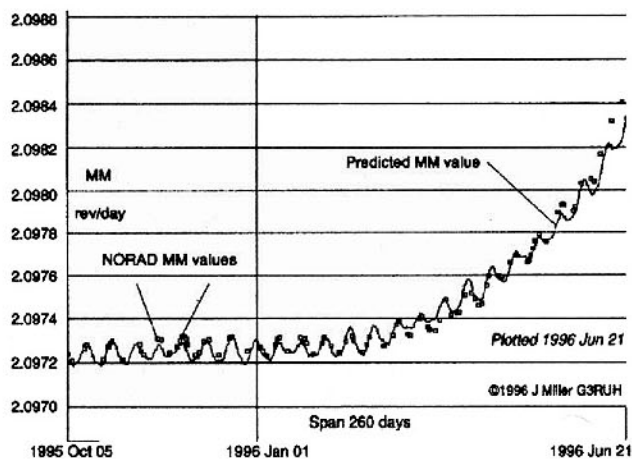


Figure 3. OSCAR 13 Mean Motion - Predicted and Actual Values.

The End Nears

Due to the differential pull of the Sun and of the Moon, OSCAR-13's orbit eccentricity began to increase in early 1994, thus reducing perigee height. In late 1996 atmospheric drag started to rob the satellite of kinetic energy, and at the beginning of December the satellite re-entered, having failed a couple of weeks before due to excessive heating.

The first evidence of drag is to be found in the record of Mean Motion, which began to increase steadily from about 1996 March 1 when perigee height was about 300 km. By September, the rate of increase was large enough to cause users difficulty in keeping tracking programs in sync.

From this time onwards, the Whole Orbit Data collection was invoked at 1 MA intervals to record solar panel temperature, right up to re-entry. A typical plot taken on 1996 November 21 is shown. By this time the temperature sensor's limit of 79C was being exceeded at almost every perigee.

The final re-orientation proposed in [3] to combat anticipated attitude changes due to perigee drag was not implemented. The observed effect was less pronounced than predicted. And because of perigee eclipses it would have taken so long to re-orient that the spacecraft would have failed mid-move. As it happened, excellent Mode-B transponder performance at ALON/ALAT = 160/0 was maintained right to the end despite a generally poor Sun angle. In fact the perigee drag torques actually improved the Sun angle, holding it to around 45° (when it would otherwise have increased to a dangerous level), and finally reducing it to 37°.

On perigee 6478/79, at around 1996 November 23 [Sat] 1140 UTC OSCAR-13's solar panel #3 ceased to function due to excessive heating.

Final Orbits

On perigee 6479/80 at around 1996 November 23 [Sat] 2009:30 UTC panels #1,2,4,6 also stopped working, leaving only panel #5. The transponders were switched off by Graham VK5AGR shortly after his AOS at 1996 November 23 [Sat] 2314:15 UTC, orbit

6480 MA 99. Orbit 6480 continued on telemetry beacon only.

AO-13 survived perigee 6480/6481, 1996 November 24 [Sun] 0432 UTC, perigee altitude 107 km, monitored by insomniacs in Europe. The battery voltage was stable at 11.8 volts, much lower than the normal 14.5V. The on-board computer and related systems are regulated to 10.0V.

VK5AGR monitored the remainder of orbit 6481, but one solar panel proved insufficient to sustain a basic system, and the beacon stopped transmitting at 1996 November 24 [Sun] 0538:16 UTC telemetry block time, orbit 6481, MA 34. Reset commands, which would have left an unmodulated carrier, had no effect.

On orbit 6482 in Europe, 1996 November 24 [Sun] 1300 UTC onwards, neither of the beacons was detected, and the Reset command was again ineffective. The command stations then concluded that OSCAR-13 was defunct.

Inspection of the very last telemetry block shows that failure occurs just as the 133rd byte was being transmitted. The spacecraft clock was reading correctly at the end, so the exact time of death, taken to be when the flight computer failed, can be recorded as 1996 November 24 [Sun] 0538:08 UTC.

Re-Entry

Re-entry was predicted for 1996 December 05/06 approximately, though experience with final orbits of decaying satellites indicates an enormous degree of uncertainty in these matters. NORAD Keplerian elements were eagerly awaited daily, while mean motion rose inexorably towards 16 rev/day.

The last element set, #387, released by NORAD was date stamped 1996 December 05 [Thu] 0842 utc and numerical integration of the equations of motion indicated that AO-13 would re-enter at about 0900 UTC, perigee 6541/2. When pressed, a Space Command Public affairs spokesman said *the predicted decay time for object #19216 / 88051B / AO-13 is 1996 December 06 [Fri] 01:57 UTC* (perigee 6552/3), and added that tracking was proving *very difficult*, a curious admission. The comment was received on 1996 December 06 at 2142 UTC, some twenty hours after Space Command's predicted decay time. At the time of writing (1997 January

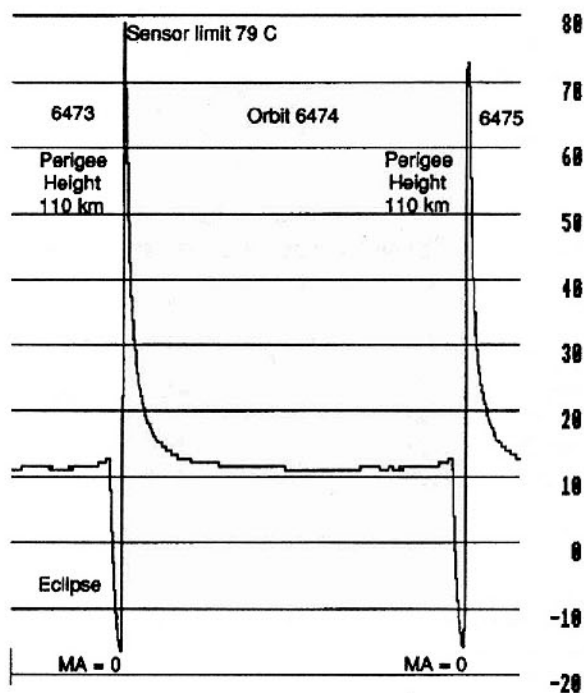


Figure 4. OSCAR-13 solar panel #1 temperature. Shows perigee eclipses and heating on 1996 November 21.

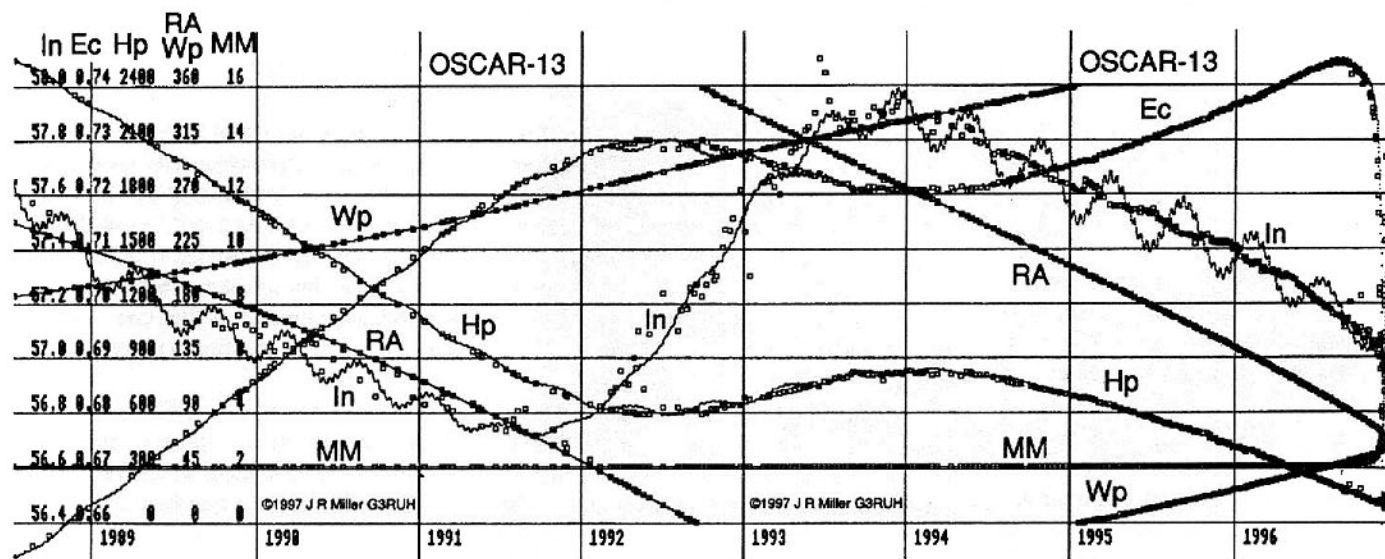


Figure 5. Evolution of OSCAR-13's Keplerian elements from 1988 July until burn-up. The culprit is eccentricity Ec which directly affects perigee height Hp. The rate of change of eccentricity and also of inclination (In) depends largely on the values of RAAN and Argument of Perigee Wp. We were unfortunate in that their initial values combined unfavourably, with the result as shown. This subject has now received a great deal of attention in order that a similar fate shall not befall the Phase 3D satellite, due for launch in 1997 [5]. Parameters computed as described in [4].

15), no official confirmation of re-entry time has been received.

Given that a) during the final 3 months, NORAD Keplerian elements were exceptionally poor when compared with expectation [4] and observation, and b) on 1996 November 03 one Space Command analyst asserted our re-entry would be January 1997, it is highly probable that AO-13 actually burned up when we predicted! This was 1996 December 05 [Thu] 0854-0900 UTC, streaking at a temperature of 3000-5000C across the USA from Denver, Colorado to the Great Lakes.

Archives

The final month was the subject of much analysis and reported day by day on AMSAT's Internet bulletin board, *amsat-bb*. Data, plots, telemetry and so on are archived in the directory <ftp://ftp.amsat.org/amsat/satinfo/ao13/>

In Figure 6 (see page 1) a final telemetry message block appeared on OSCAR-13 a couple of days before the spacecraft failed.

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AO-10 Keplerian Elements

Stacey Mills, W4SM & Ken Ernandes, N2WWD

Most AO-10 users have noticed that the most currently available AO-10 Keplerian elements dated 96-299 are getting quite old. While many AMSAT members have been discussing this problem, the short answer is that **there are no new Keplerian elements**. New NORAD-generated elements will not be available until Spring or early Summer 1997.

The last NORAD elements for AO-10 from 1996/day 299 list Decay: $-3.05e-06$ rev/day² (-0.00000305) and Epoch time: 96299.11613815. Note the negative decay which means orbital energy was **apparently** increasing and mean motion was **apparently** decreasing. Negative decays are usually short-term blips due in part to short-term fitting/fudging of vector data. Apparent negative decays don't last very long, and disappear if one smooths over a large set of elements. After all, energy isn't **really** flowing into the orbit.

The fact that the last rather old set of AO-10 elements includes one of these negative decay blips that has gone unrevised for quite a while is the source of the current problem with tracking AO-10. The current elements are considerably later than reality, because they erroneously assume a negative drag with gradually increasing mean motion, and this error has been accumulating for quite a few days/months now.

I had previously found that subtracting 0.02 days from epoch time gave Keplerian elements that worked pretty well. Jeff Garrett, Ian Ashley and others in New Zealand did some ranging measurements on AO-10 and determined that changing the Decay (drag) value to: 0.0000001 (+1.0 e-07) resulted in elements that were very close to their ranging values. This is probably the easiest and best change to make, i.e. leave Epoch Time alone and change the old decay of $-3.05e-06$ to $+1.0$ e-07. Some tracking programs won't go to the precision of e-07 and will treat decay as "0." That's fine and still much better than the old value.

On the WISP software, this has the effect of adding about 10 MA units to the orbit, which is in close agreement with my Epoch-time altered elements (subtracting 0.02 days from Epoch time adds 10.5 MA). So either way works short-term, but altering the decay gives elements that will stay accurate longer, which is the better approach. I have recently tested these elements with AOS/LOS and eclipse observations that indicate they are very close; plenty close for our purposes.

We have also found that zeroing the drag works just fine. These **revised AO-10 Keplerian elements** are provided in the Orbital Elements section on page 17 of this issue of *The AMSAT Journal*. ■

AMSAT-Italy Tutorial

Paolo Pitacco, IW3QBN (pitacco@imc12.univ.trieste.it)

During the last year, AMSAT-I took a series of steps to increase its presence in the Italian and International amateur space arenas. The results are already showing up with a renewed interest in AMSAT-Italy as a whole and, consequently, space activities. This article will describe some of AMSAT-Italy's activities and their current status.

Services: To continue support of satellite operations and to extend our reach keeping members and would-be members in touch with us, we have started new services mainly concentrated around an Internet WWW site. This site, http://www.aec2000.it/amsat_i is growing constantly and is so effective (and inexpensive to maintain) that our packet BBS has been shut down and its data transferred to our WWW site. The WWW site is mainly in Italian but some of the pages, of more general interest, are in English too. Between them is a nice searchable data base containing data on *all* artificial satellites beginning with Sputnik in 1957 and up to 1993. These data have been kindly provided by Dr. T. S. Kelso. Another service started is a series of publications devoted to different aspects of satellite operations and design. Between them is our bi-monthly publication, *AMSAT-I News* which after the addition of many features it is now a full size magazine.

Technical articles are mixed with operating tips as any AMSAT magazine. However, we devote a good part of it to information about manned and unmanned space programs that could have an impact on amateur activities or that we consider should be part of the know-how of any space enthusiast.

Designs: A single board 16-bit computer, based on a 80186 microprocessor has been designed that is programmable in high level languages with any commercial DOS or Windows® compiler. The board, known as SBCC 186, is a general purpose design which supports up to four serial communication ports individually programmable even for high speed packet operations. ROM software solves many tasks such as LCD driving, parallel I/O driving and principal KISS protocol implementation. A prototype has been developed that is currently running as a stand-alone tracking and antenna slewing system called *SkyTracker* (by IK4IRO). A smaller version has also been developed and it is based on an 8-bit 80188 microprocessor. Like the 16-bit microprocessor, this will soon be available in a kit with PCB & EPROM and manual.

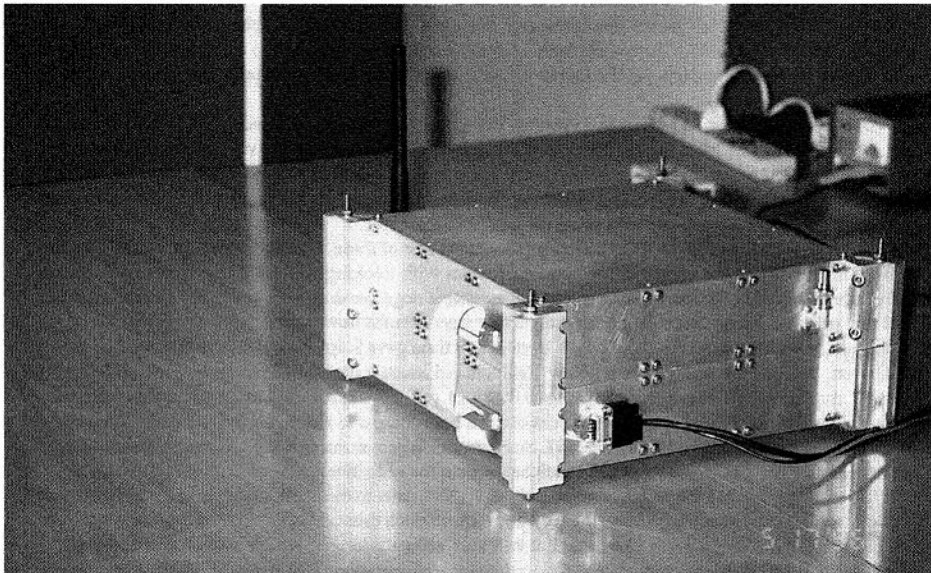
Pushing towards S-Band operations, a *no tune* 2400 MHz to 430 MHz, or 144 MHz, receiving converter has been

designed making use of a reduced number of modern components. Less expensive than many other units, this converter will be sold by AMSAT-I as a pre-assembled kit. We will be able to provide a preamplifier and filters in advance for the most demanding operators, as the converter has been designed as a core for more complex applications.

A companion low-power transmitter has also been designed which provides a fixed frequency (quartz and PLL controlled) which integrates on the PCB a printed *antenna* that could be separated in case of need. This transmitter can be easily modulated for audio or FSK operations and will be ideal for modes like spread spectrum.

AMSAT-I Transponder: A *simulated satellite* with analog transponder, digital telemetry, and command links has been designed and assembled using RF modules built years ago for another similar project. This time, however, the system is a hybrid between a Microsat and a Phase II analog satellite. An analog Mode B transponder has been designed with a digital telemetry (TLMD format) channel which transmits Microsat style packets at 1200 bps in BPSK. The transponder is housed in newer and wider Microsat-style modules. These modules can be the basis for a future satellite and the whole transponder has been implemented with this idea (refer to photo). A third module not shown in the photograph has been made and is housing a GPS receiver and a version of our low-power S-Band transmitter. All the modules are connected through a standard Microsat AART bus. Presently, a new bus for satellite applications is under study. New modules can be quickly added and the next one will probably be a battery and power management unit. Another interesting peculiarity of this transponder is a multichannel IF system (AGC and OBC controlled) that can be used to reduce the effects of powerful ground station signals.

Presently, this transponder is considered a *ground travelling satellite* built to help local area amateurs learn about analog and digital mode satellites. Plans are underway to operate this ground travelling satellite in several locations throughout Italy. In addition, for wider coverage, it can



A Ground Travelling Satellite: One module houses all of the RF equipment which is controlled by a second module, the on-board computer which contains a SBCC 186 board. The on-board computer manages the operations of the whole assembly and will be able to handle more than one digital channel along with housekeeping chores. It can be easily reprogrammed remotely.

be operated aboard aircraft and can also be equipped with solar panels for autonomous operations.

Education: Education is a major topic that AMSAT-I is pursuing on general and technical levels. For example, a full set of documents that describes amateur satellite operations, communication modes, orbits, ground stations, and etc. is being produced for availability to members.

In May 1996, we organized and conducted a major congress at the University of Rome. The congress was devoted to many aspects of *Radio in Space* and between various papers, a special section was devoted to GPS technology and its applications. Following on this theme, a one-day microsatellite technology workshop will be held this year at the University of Rome in cooperation with the Italian Aeronautics and Astronautics Association and others will follow.

Our bi-monthly magazine, with its widespread content, is also fulfilling an informative role on space activities which is badly missing in Italy.

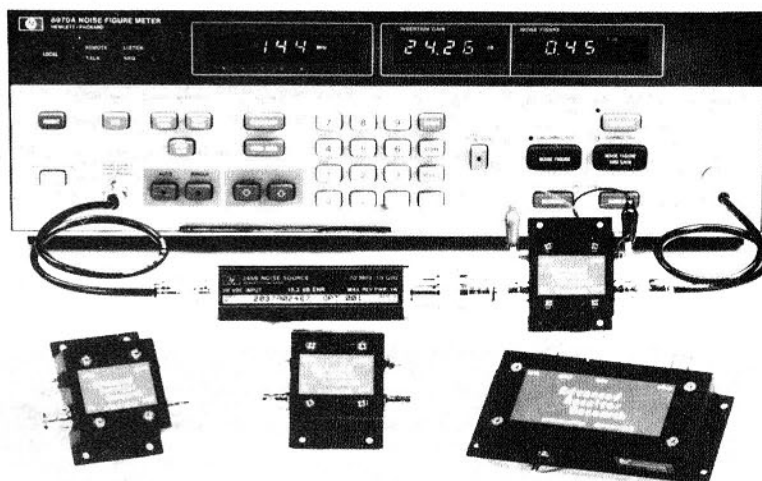
Conclusions: AMSAT-Italy will continue its efforts to enhance S-Band operations and to take its travelling satellite transponder on the road. A new main task will be to set up services that encourage and enable the use of Amateur Radio in schools to let students get first-hand experience with space activities. In this regard, AMSAT-I looks forward to participating in the ARISS project. We believe AMSAT as a whole, has a unique capability of being able to use Amateur Radio to *bring space to the people* while other organizations can only *show it*. As a result, AMSAT-Italy is once again on the road toward implementing this capability.

Editor's note: Some amateurs identified in the AMSAT-Italia Pictorial which appeared in the September/October issue of The AMSAT Journal were not current AMSAT-I members. Since then, these persons have renewed their AMSAT-I memberships. We apologize for any embarrassment this has caused. As a result of discussions on this matter, Paolo provided the above article that describes AMSAT-I activities. ■



AMSAT-I members at Congress held last May at the University of Rome La Sapienza. Top row from left: Bruno, Tonino, Leo IK0REK, Roberto IV3JDV, Massimiliano IW3QCV, Vittorio IK4IRO (with SkyTracker box in hand). Front row from left: Fabrizio ex-I0QIT, Paolo IW3QBN, AMSAT-I President.

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P144VD	144-148	<1.5	15	0	DGFET	\$29.95
P144VDA	144-148	<1.0	15	0	DGFET	\$37.95
P144VDG	144-148	<0.5	24	+12	GaAsFET	\$79.95
P220VD	220-225	<1.8	15	0	DGFET	\$29.95
P220VDA	220-225	<1.2	15	0	DGFET	\$37.95
P220VDG	220-225	<0.5	20	+12	GaAsFET	\$79.95
P432VD	420-450	<1.8	15	-20	Bipolar	\$32.95
P432VDA	420-450	<1.1	17	-20	Bipolar	\$49.95
P432VDG	420-450	<0.5	16	+12	GaAsFET	\$79.95
Inline (rf switched)						
SP28VD	28-30	<1.2	15	0	DGFET	\$59.95
SP50VD	50-54	<1.4	15	0	DGFET	\$59.95
SP50VDG	50-54	<0.55	24	+12	GaAsFET	\$109.95
SP144VD	144-148	<1.6	15	0	DGFET	\$59.95
SP144VDA	144-148	<1.1	15	0	DGFET	\$67.95
SP144VDG	144-148	<0.55	24	+12	GaAsFET	\$109.95
SP220VD	220-225	<1.9	15	0	DGFET	\$59.95
SP220VDA	220-225	<1.3	15	0	DGFET	\$67.95
SP220VDG	220-225	<0.55	20	+12	GaAsFET	\$109.95
SP432VD	420-450	<1.9	15	-20	Bipolar	\$62.95
SP432VDA	420-450	<1.2	17	-20	Bipolar	\$79.95
SP432VDG	420-450	<0.55	16	+12	GaAsFET	\$109.95

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Portable Voice Satellite Station

Chuck Duey, KI0AG, ki0ag@amsat.org

If you are on the go or cannot spare the space for a good rotator system, you might want to consider jumping into AO-27 portable action. AO-27 can be operated with a minimal amount of equipment that when packed together is small enough to slip into an overhead bin or the trunk of a rental car. Also, AO-27's sensitive receiver makes uplink easy from just about anywhere in northern hemisphere. The downlink and the Doppler shift are the only difficult parts of operating this *portable satellite station*.

In the northern hemisphere, AO-27 is an FM repeater during the daytime passes. Despite its one channel and its brief 10-15 minute passes, AO-27 handles many contacts. There are quite a few mobile and portable stations that work AO-27 from rare and unique grid squares. Also, on weekend passes as many as 30 stations work AO-27 during a pass, making it difficult to get in even from rare grid squares. Weekdays are a bit better, but not as many people are traveling around.

AO-27 has a downlink frequency of 436.800 MHz and an uplink frequency of 145.850 MHz. On a typical pass the downlink frequency starts at 436.805 MHz and decreases from there due to Doppler shift. The uplink frequency normally does not need to be compensated for Doppler shift as the FM receiver is very wide and sensitive. At the end of the pass a user's downlink frequency will be near 436.785 MHz. Currently AO-27 is only active during daytime passes in North America when the satellite is on a descending node.

The equipment to run AO-27 can be as simple as an HT with a rubber duck. However, the problem with a rubber duck antenna is that AO-27's downlink signal can only be clearly heard about ten percent of the pass. Meanwhile, because of AO-27's uplink sensitivity, an uplink signal can get in most of the pass. So a rubber duck antenna turns into the QRP alligator (*all mouth and no ears as signals can get into the bird but the operator cannot hear the satellite*) station quite quickly. However,

with some practice and a few adjustments an HT works, but the reliability of the contacts can be very frustrating on both ends.

An advanced portable station step-up for AO-27 is to use a small 70 cm beam to receive the bird and a rubber duck or whip antenna for the uplink. This setup works well for the downlink. In fact, a five-element or better Yagi antenna works well picking up the bird from horizon to horizon. However, if you have ever heard AO-27 in the southern latitudes of the US, there is quite a bit of terrestrial interference on the uplink frequency. Sometimes five Watts into a rubber duck or even a good whip cannot make it in over this QRM. If you are using a mobile radio, it is easy to increase power when this situation occurs, however most HTs are usually limited to five watts for practical and safety reasons.

As a result, this brings up the use of the dual band Yagi antenna for portable AO-27 operations. On a boom, a Yagi antenna consisting of three 2-meter elements and five to seven 70 cm elements fits quite nicely. While having the two beams in the same polarization will work, it gives some interesting lobes that make it difficult to hand track the bird. Cross polarizing the two Yagis reduces the interference and still gives a very good uplink signal. The advantage of a dual band antenna is that you can add an HT with headphones allowing and you to walk around just about anywhere making contacts. However, a big disadvantage is there are no hands free to write contact information such as callsigns, QTH location, time, and etc.

A dual band Yagi can be quite cumbersome to transport or assemble. There are some antennas like the Arrow Antenna that are designed for quick assembly and breakdown. With a good quick setup antenna, a dual band HT and some headphones in a carrying case, it becomes easy to transport the entire station crosscountry.

Figure 1 shows the complete satellite station that can be stored in a flyfishing rod case. The antenna is an Arrow 146/440-8 (arrow146@aol.com) and the radio is a Yaesu FT-530. Also pictured and included in the case are headphones, duplexer, and GPS. The elements fit nicely into the foam

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rubber for protection and there is no strange rattling in airports. Also the complete system does fit in every overhead bin that I have encountered. Just be ready to open it up at security. The assembly of the antenna typically takes a leisurely three minutes, or 60 seconds if you are in a hurry and can operate horizon to horizon even on a five degree pass. Figure 2 shows the system assembled and ready to make AO-27 contacts.

Before a typical trip, I usually run my favorite tracking software to get AO-27 pass times for my destination. Also the Internet Worldwide Web site <http://acsprod1.acs.ncsu.edu/scripts/HamRadio/sattrack> can also provide AO-27 pass times. To start operating a good location is important. A park with open spaces or a rest stop along the highway usually work if there are no commercial transmitters close by. Tune the radio for 145.850 MHz transmit and 436.805 MHz for receive. Turn down the volume and turn up the squelch on the 2 meter side and open the squelch and adjust the volume on the headphones for the 70 cm side. At the start of the pass point the antenna with the 70 cm elements vertical. (AO-27 typically rises from the North.) The first thing heard is a quieting of noise, but *wait*. A few seconds after the quieting, voices can then be heard. The AO-27 pace can be quite quick and the best way to get a contact is to listen for a station who seems to hear the bird well. Call that station, just putting out a call sign may not get a reply. Quite often there are stations getting in very well but cannot hear the bird (*an Alligator!*). As the satellite passes, track it by moving the antenna a little and listening for the best signal. An S-meter can also help to fine tune the position. At about three minutes move the receive to 436.800 MHz, then three minutes later to 436.795 MHz. The 436.795 MHz is short-lived of only about one minute. The next step 436.790 MHz lasts about three minutes and 436.785 MHz lasts the remainder of the pass. Typically the transmit stays at 145.850 MHz, but towards the end of the pass QRP stations do a little better with a shift to 145.855 MHz. Immediately after the pass make sure to write down all the contacts, record the time and location as it is easy to forget contacts as time passes.

Typically the tear-down takes a few minutes. However, quite often in new locations someone will approach and ask what you are doing. Many times they think

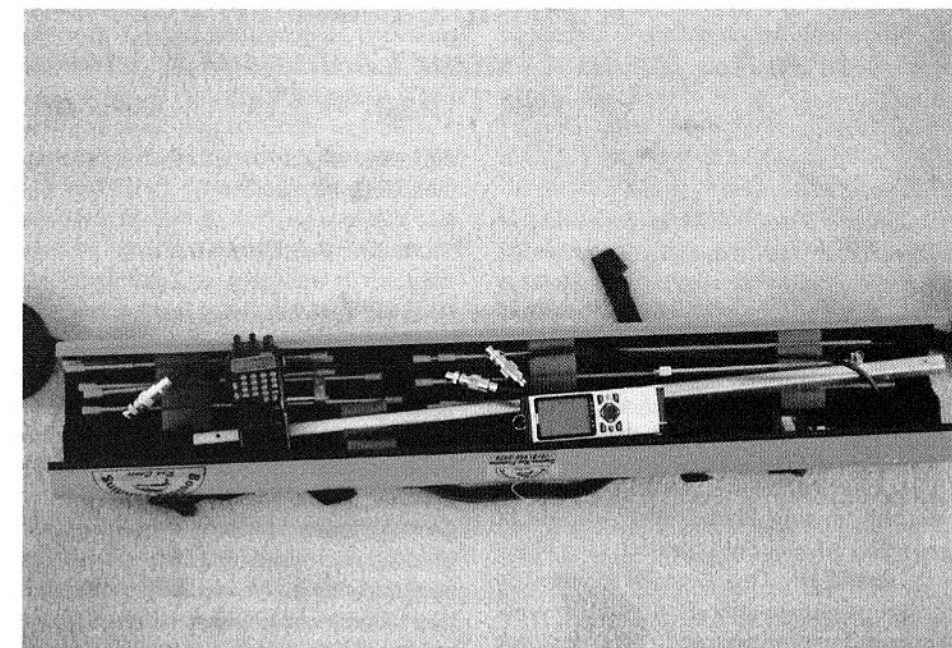


Figure 1. KI0AG's AO-27 portable satellite station consisting of an Arrow 146/440-8, Yaesu FT-530, headphones, duplexer, and GPS. The unit is stored in a flyfishing rod case. (KI0AG photo)

your tracking an animal or bird; *"Yes, it was a bird of sorts, an Amateur Radio Satellite."* You may also want to mention the QTHs contacted on that pass.

My setup has been quite useful in portable operation as I have successfully used it on 14,000 ft mountains and on the beach. Everyone who has run a setup like this has enjoyed the experience of portable

operation too. Just watch out for cold winds giving frostbite and thunderstorms! After a lightning strike about 150 yards away while operating, I no longer operate if there is any lightning or thunder within five miles.

Catch you on the Birds, 73,

Chuck (KI0AG) ■



Figure 2. The real KI0AG with portable AO-27 satellite station in operation. (Editor's note: Will the real KI0AG please standup? The photo that appeared in KI0AG's last article published in the November/December issue of The AMSAT Journal was actually Dave Reed, NK4R of Westminster, CO. Fortunately both KI0AG and NK4R have humorously discounted the mistake and accuse each other being an evil twin brother.)

A Possible Phase 3D Follow-on Project:

A Proposal for an Amateur Continuous Worldwide Communication Facility

Bill Tynan, W3XO (w3xo@amsat.org)

Editor's Note: W3XO has asked that we make it clear that, in making this proposal, he is speaking for himself as an individual AMSAT-NA member - not as its President, or a member of its Board of Directors. The views W3XO expresses may or may not be shared by other Board members.

Quite a bit of discussion has occurred recently, in this Journal and elsewhere, regarding what our next project, after Phase 3D, should be. This paper is intended to further stimulate that discussion, present various possibilities and proposes one specific idea. It describes a system of from one to three geosynchronous, or near-geosynchronous spacecraft. The satellite, or satellites would draw heavily on existing technology and they would employ the simplest possible design to accomplish the objective. That objective would be to provide instantaneous, full time amateur satellite communication. If three such spacecraft can be built and launched, communication would be worldwide. Otherwise, service would be available to

the part of the world that builds and launches each satellite.

Our Ultimate Goal

Ever since I attended that January 1969 meeting in Perry Klein's apartment in Southwest Washington, DC, which resulted in the founding of The Radio Amateur Satellite Corporation, I have believed that the ultimate goal of the amateur space program should be to provide hams all over the world with continuous, real-time, 24-hour per day communication. I understood and agreed that other less ambitious satellite systems would, by necessity, have to precede achieving that goal; but I have always been convinced that providing this kind of service for Amateur Radio should remain the amateur space community's ultimate objective.

Various Potential Approaches

There are various ways in which this goal can be achieved. The most obvious is the approach taken by commercial satellite operators - the use of geostationary

satellites. For real-time, continuous, worldwide coverage; three such spacecraft located close to 120 degrees apart around the globe would be required, along with some kind of relay between them. Relaying can be accomplished either by direct links between the satellites or through appropriately located ground terminals.

Another potential approach to achieving the objective is through the use of many low earth orbit (LEO) satellites. Various commercial systems of this type are ready to begin launches very soon. The best known of these is Iridium, being promoted by Motorola and a number of the world's telephone companies. LEO satellites have the advantage of less signal loss between the ground users and the satellites. Thus, it is possible to access the system with low power handheld transceivers, much like cellphones. We amateurs actually pioneered the use of LEO satellites for communication when the private sector had all but given up on them as useless. As early as 1972, the potential for low earth orbit analog communication was shown by AMSAT OSCAR-6 and later by AMSAT OSCARS 7 and 8. The



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MICROSAT, UoSAT and Fuji series of amateur satellites demonstrated the utility of LEO spacecraft for relaying digital data from one part of the world to another. First, AO-21, and more recently AO-27 and SAFEX, have been used to relay FM voice communication using groundstation equipment down to handhelds. Now, there are many commercial companies which wish to exploit the data relay capability pioneered by us amateurs, and are even eyeing our frequencies as potential spectrum allocations in which to do it.

For any LEO system to accomplish worldwide real-time communication, numerous inter-satellite relays must be provided. Each spacecraft serves only an ever-moving circular footprint, the size of which depends on its altitude. As with the three geosynchronous spacecraft case, this relaying can, in theory, be accomplished by direct linking between satellites or through ground terminals. However, with the LEOs a large number of relays must be provided. If ground terminals are used, many such stations would have to be set up in numerous locations, including some very out-of-way places around the world. Relaying between satellites would require considerable complexity in the spacecraft as well as consuming a significant portion of the available power. There is a significant difference in complexity of a LEO system if its intent is merely to provide non-real-time data relay (flying mailbox service), or communication only to each spacecraft's footprint; as opposed to wide area real-time communication.

In my opinion, the ultimate objective of the amateur community should be to provide the capability for 24-hour-per-day communication between licensed amateurs throughout the world - preferably without dependence on commercial communications facilities. One approach to an amateur LEO system was the subject of a paper presented at the 1995 AMSAT Space Symposium. [1]

Aside from LEOs and geostationary, or geosynchronous satellites, there are other potential ways to accomplish real-time nearly continuous communication throughout the world. One might be two or more drifting near-equatorial orbit satellites similar to the orbit used by the French amateur radio satellite Arsene. Three such spacecraft in orbits slightly higher or lower than geostationary, can provide continuous

worldwide coverage if relays are used. This approach has the advantage of providing wide area access for part of the time, even with only a single spacecraft. Thus, part-time wide area coverage capability is achieved with the successful launch of the first spacecraft. The disadvantage of this approach is that ground station antennas must be continually re-pointed to access whichever satellite is in view at the time. This is not a huge disadvantage for fixed stations. Many amateurs are already doing this with the aid of their computers, appropriate software and rotator control hardware. In the case of mobile and portable installations, such an approach is generally not practical. But, if the satellite(s) provide sufficient transmitter power and antenna gain, even mobile installations (but not handhelds) may be able to have communication, although at a lower quality than fixed stations using higher gain antennas. Phase 3D will give us the opportunity to evaluate this capability.

Another possible approach to providing worldwide coverage is several spacecraft in orbits similar to those used by the GPS constellation. These satellites are in near polar orbits at about 20,000 km (12,000 miles). Three amateur satellites in such orbits would provide continuous coverage and two would provide near-continuous coverage. An advantage of this type of orbit is that it affords coverage of the poles, which any equatorial orbit does not. Also, the path loss is less than that associated with geostationary, or near-geostationary altitude, possibly eliminating the necessity of gain antennas on the ground and the associated antenna pointing requirement. Such satellites would have to be somewhat more complex than geostationary or near-geostationary satellites because of the need to keep their antennas pointed toward Earth. Gravity gradient stabilization is one, relatively simple, approach to solving this problem. The GPS spacecraft accomplish it through the use of reaction wheels, similar to those used in Phase 3D.

Last but not least, the orbit we have been using for years cannot be overlooked. This is, of course, the very elliptical Molniya orbit pioneered by the Soviets and used by AO-10, AO-13 and soon for Phase 3D. Certainly, several Phase 3D type spacecraft in properly spaced orbits could, with ground relays, be capable of providing worldwide real-time coverage. Ideally, some of these satellites might have apogees

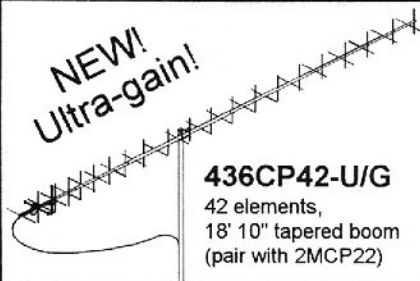
in the southern hemisphere, rather than the northern hemisphere as will Phase 3D. The use of Phase 3D-like spacecraft would, of course, necessitate all the complexities of Phase 3D, but the engineering work would already have been done. On the plus side is the fact that Molniya orbits, like Phase 3D's affords the opportunity to unload the reaction wheels at perigee by use of the magnetorquing rods interacting with the Earth's magnetic field.

Don't Bite Off More than We Can Chew!

In the many, and sometimes protracted, discussions the AMSAT-NA Board has had on the subject of post-Phase 3D projects as well as other musings on the subject, the caution has been advanced that, anything that is done in the way of building satellites beyond Phase 3D, must have simplicity as the watchword. An often repeated guideline is that the project should be one that can be completed in three years or less, as it is difficult to keep volunteers focused on an effort that is of much longer duration than that. There is no doubt that Phase 3D is not simple and it has taken over five years to complete. But, Phase 3D was never advertised as simple. Its complexity stems from the missions envisioned for it. Principal among these is to bring practical satellite communication within the reach of as many licensed hams throughout the world as possible. This dictated three axis stabilization with high gain antennas, always pointed toward Earth, and the solar panels, always pointed toward the sun. High gain antennas are needed so that lower performing groundstation equipment than that normally employed with AO-10 and AO-13, can be used. That objective also dictated the use of higher power transmitters than those used on previous Phase 3 satellites. Multiple high power transmitters, especially in view of the fact that it is desired to power up more than one at a time, dictates the use of large deployable solar arrays. The fact that the solar arrays must be deployed is another factor which adds to Phase 3D's complexity. Phase 3D is also intended to serve as a transition to the higher amateur bands while providing capability on the bands presently used for satellite work. As such, it is equipped with five matrix-connected transmitters from 145 MHz to 24 GHz, and nine receivers from 21 MHz to 5 GHz. The IF matrix permits any of these receivers to be connected to any

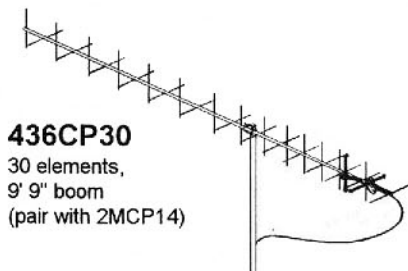
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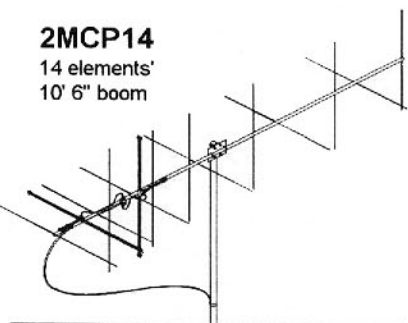
436CP42-U/G

42 elements,
18' 10" tapered boom
(pair with 2MCP22)



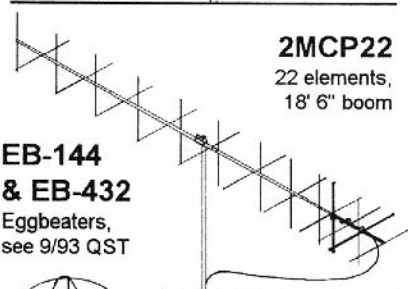
436CP30

30 elements,
9' 9" boom
(pair with 2MCP14)



2MCP14

14 elements
10' 6" boom

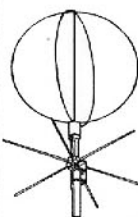


2MCP22

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transmitter and, in fact, several receivers and transmitters can be operated simultaneously. To borrow from an oft repeated cliché, from the 1996 U.S. Presidential campaign, Phase 3D will *serve as a bridge to the 21st Century*, in this case by encouraging the use of and demonstrating the advantage of, the higher bands for satellite communication. The commercials already know this. Many forward-thinking amateurs believe that it is high time the rest of us realize it too.

Phase 4 - A Little History

During the latter part of 1980s an active study was undertaken by AMSAT-NA to design a geostationary amateur satellite. It was dubbed *Phase 4*. The design that was produced cannot be characterized as simple, any more than Phase 3D is. It was to include bands as low as 2 meters and hence have large deployable Yagi arrays. These ungainly antennas had to be stowed before launch and during early flight; and deployed after the spacecraft's separation from the launch vehicle. Also required was a method of keeping these antennas pointed toward Earth while the satellite traversed its orbit. Yes, geostationary satellites do orbit! It was recognized that the type of Phase 4 spacecraft envisioned would be large, complicated and expensive. The total cost was estimated at about \$4,000,000. Since Phase 4 was to serve only North and South America, this entire sum would have had to have been raised from the Western Hemisphere. There was also no identified launch opportunity. Various approaches, including the Shuttle, were discussed as possibilities, but that is as far as it went.

In the light of all of these obstacles, not the least of which was the funding challenge; the AMSAT-NA Board, in 1990, decided to drop all effort on the Phase 4 Project. The other reason for shelving Phase 4 was that the Board concluded that a more achievable goal would be to join our German compatriots on the Phase 3D Project. Much design work had already been done and Karl Meinzer DJ4ZC and his associates had already succeeded in raising well over \$1,000,000 to support the project and had identified a launch opportunity. So, to keep AMSAT-NA in the satellite building business and do our part in providing amateurs with a significant new capability, the AMSAT-NA Board opted to participate fully in the Phase 3D Project. I was a member of the Board at the time and

believed, as the other members did, that this was the best course we could follow. I remain convinced that this was the correct decision under the circumstances.

As most AMSAT members must be aware, Phase 3D has been our all-consuming endeavor since that time. With significant help from ARRL, we have raised well over \$1,000,000 here in North America in support of the Project. We have also been very active in the design of the spacecraft itself and in its integration and testing. We have provided some of the key electronic modules including construction of the IHU (the spacecraft's central computer), the RUDAK computer, the GPS experiment and several smaller electronic subassemblies.

A Proposed Approach

If the ultimate objective of the amateur satellite effort is to provide 24 hour per day, worldwide coverage, the use of three appropriately placed geostationary satellites seems to be the most obvious choice - and is probably the most desirable from the user point of view. A plus for this type of orbit is that most launches go to geostationary transfer orbit (GTO). However, geostationary satellites present some significant complexity issues. For one thing, if true geostationary performance is to be achieved, some means of station-keeping must be provided to precisely maintain the satellite at the exact geostationary altitude, above the equator and at its intended longitude position. To accomplish this, commercial geostationary satellites carry on-board propulsion systems, usually employing cold gas. An important factor in determining the life of such satellites is the amount of station-keeping propellant they can carry. Some means of directing the firings of stationkeeping jets in the proper direction for each firing must also be provided.

Keep it Simple

In all of the discussions on possible follow-on projects, the watchword has been - *keep it simple*. Some have used this as justification for rejecting geosynchronous, or any relatively large high altitude, satellites altogether. In fact, the contention is made that much more than quite small spacecraft, typified by the MICROSATs and UoSats and providing fleeting real-time communication or store-and-forward

service, is all that AMSAT should even think about attempting in the years to come. Others contend that the Phase 3 spacecraft has proved that amateurs can successfully tackle quite complex expensive projects.

While geosynchronous satellites do present complications, so do many other concepts. A geostationary satellite is more complex than a geosynchronous satellite. That is why the term *geosynchronous* has been used in this paper rather than *geostationary*. A geostationary satellite must be located precisely above the Earth's equator and have exactly the right orbital velocity to keep it orbiting at the same angular velocity as that of the Earth's rotation. This infers precise placement into the right orbit in the first place and precise stationkeeping once there. On the other hand, a geosynchronous satellite may have an orbit which is somewhat inclined and thus trace out a figure "8" back and forth across the equator. Much less in the way of stationkeeping precision is required to maintain this type of orbit. Of course, depending on how inclined the orbit is and the beamwidth of ground based antennas, they may have to be re-positioned from time to time to keep at the satellite within the beam.

To keep the complexity of the satellite(s) as low as possible, geostationary spacecraft are not proposed for this application. Instead, a system consisting of a constellation of one to three geosynchronous satellites is suggested. This approach will be the subject of the rest of this paper. An alternative is the use of about three near-geosynchronous satellites. Such satellites would drift around the world, much like the French amateur satellite, Arsene.

As emphasized in all the discussion on follow-on projects, any spacecraft considered must employ the *KISS* principal. It is vital that every effort be directed toward keeping the satellites as simple as possible, even at the expense of adding some complexity on the ground. Some of the ways in which it is proposed to accomplish this are as follows:

- The satellite(s) will be in a geosynchronous, rather than a geostationary, orbit. An alternate approach will be studied that would put one or more spacecraft into near-geosynchronous orbits, causing them to drift around the Earth.

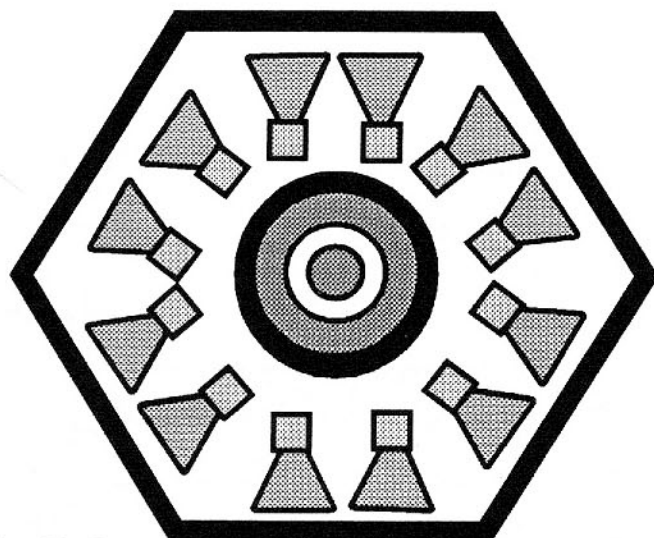


Figure 1. Motor-side of proposed near-geostationary satellite showing twelve horn antenna.

- Only a few frequency combinations will be supported (possibly a single uplink and a single downlink).
- Only microwave frequency combinations will be used.
- The spacecraft will spin.
- Any stationkeeping system needed, should be as simple as possible and should take advantage of existing technology. It should not require re-orientation of the spacecraft before and after stationkeeping operations.
- Antennas will be directed toward Earth (de-spun) without the use of moving parts.
- Ground based linking between satellites will be used rather than direct satellite-to-satellite links.
- Every possible advantage will be taken of existing designs.

Let's look at these points one at a time and see why each is important to keeping the cost down and making the project achievable.

As already discussed, true geostationary satellites must have precise station-keeping capability. A geosynchronous satellite has much less need for precision in this regard. A satellite that is allowed to drift, may not require station-keeping at all, although if more than one such satellite is orbited, there is a need to keep them from bunching together.

Simplicity of design dictates that the proposed satellite not attempt to cover a wide range of bands as Phase 3D does. Limiting it to microwave frequencies makes high gain spacecraft antennas smaller and simplifies their de-spinning as well as leading to significant simplification of the spacecraft's mechanical design. The use of the microwave bands also affords the wide bandwidth (5 to 10 MHz) considered necessary to support a large number of users and permit wide bandwidth - high data rate communications capability.

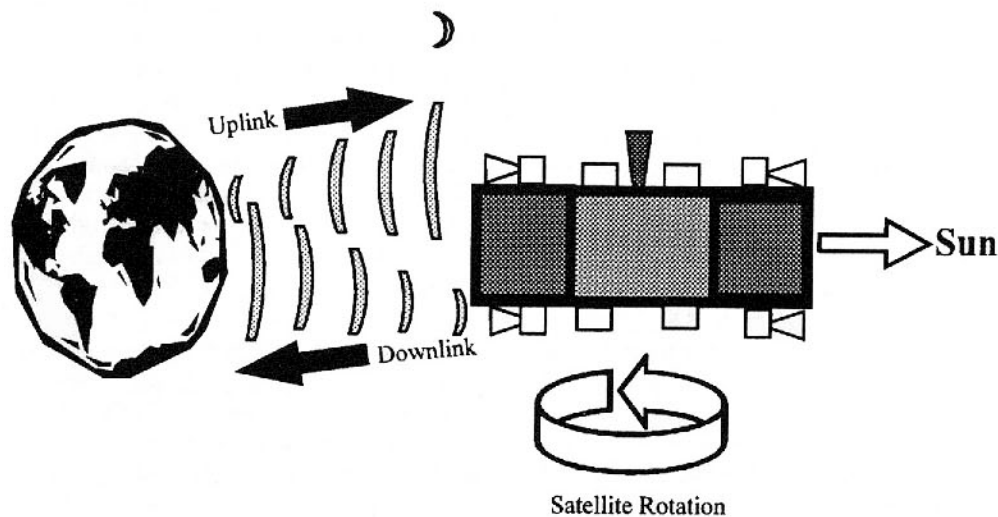


Figure 2. A sketch of how the near-geostationary satellite might be positioned in space.

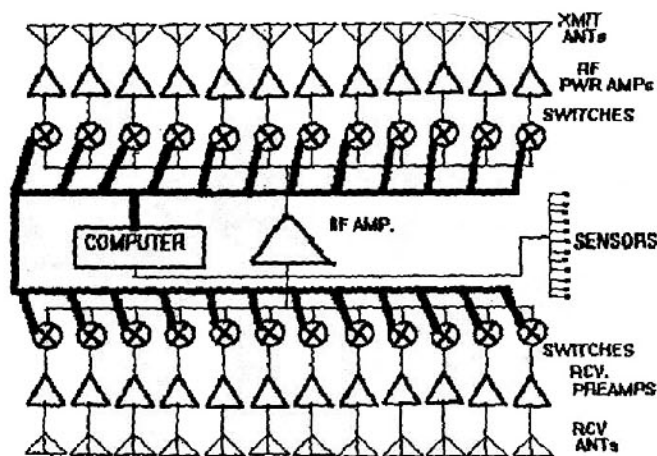


Figure 3. Block diagram of proposed near-geostationary satellite.

It is envisioned that spread spectrum techniques may well become an increasingly important approach to efficiently using the type of facility envisioned.

Keeping the number of frequency combinations low also simplifies antenna design and minimizes the need for switching. Incidentally, it simplifies groundstation requirements as well, as fewer uplink/downlink combinations are needed.

It is believed that Phase 3D will make microwave operation more palatable to the user community than it is today. The reason for this is, as already noted, that it should serve as a *bridge* between what we now have and what we will have, and be comfortable with, five to ten years from now. By including equipment for 2 meters and 70 cm, as well as the microwave bands, Phase 3D will demonstrate the superiority of the microwave bands for satellite communication. Its very presence will encourage experimenters and commercial firms to come up with simple, inexpensive microwave gear. Thus, in the next three to five years, much more microwave equipment suitable for satellite use will become readily available and at considerably less cost than today. This should lead to such equipment being in many more shacks than is currently the case.

Spinning the spacecraft eliminates many problems. There will be no need for moving parts such as the reaction wheels used in Phase 3D. Although the heat pipes

used on Phase 3D are not particularly complicated, they are somewhat costly. Spinning the satellite eliminates the need for heat pipes as the spin causes the heat to be distributed around the spacecraft. Almost all the commercial geostationary TV and telephone relay satellites are spinners.

Nevertheless, the spacecraft spinning carries with it several disadvantages. First, considerably less power is generated by the solar arrays (approximately one third as much). This is one driving force behind not proposing multiple transmitters running simultaneously on various bands.

It is certainly more difficult to accomplish stationkeeping on a spinning spacecraft. A lot of complexity is added if the satellite must be re-oriented for every stationkeeping motor firing. One approach might be to use one or more arc-jets of the type used on Phase 3D. This could be pulse fired every time the spacecraft spins past the proper direction. While the full capability of the arc-jet would not be realized with this method, it might be enough to handle the small amount of delta velocity needed to keep the satellite at the correct orbital velocity/altitude. Obviously more study is needed on this.

A spinning the spacecraft also requires some method of keeping the antennas always pointed toward Earth. The commercial satellites do this with an electric motor driving the platform, on which the antennas are mounted. This motor is run at a speed equal to the satellite's spin, but in the opposite

direction. The equipment mounted on the platform must, of course, be connected to the rest of the spacecraft through slip rings. This adds complexity and decreases reliability.

For this proposed amateur near-geostationary satellite(s), a group of 12 radially directed antennas, probably horns, will be mounted on the top plate of the spacecraft and 12 more antennas on the bottom plate. (See Figures 1 & 2.) One set of antennas will be for receive and the other set for transmit. All of these antennas will be fixed to the spaceframe. As the satellite spins, the antennas facing Earth at the time will be switched ON and all others will be OFF. For the transmit side, it is anticipated that this switching process would be done at a low RF level using PIN switches or similar devices. This will entail the use of multiple power amplifiers, each feeding its own antenna. The use of multiple power amplifiers will increase cost somewhat, but it will also provide some redundancy. Severe QSB would result if a power amplifier should fail, but communication would still be possible. To conserve power, the amplifiers not in use will be biased to draw little or no current. The use of these multiple amplifiers might seem to increase complexity, but since all will be identical, only one design effort is needed. The various amplifiers could be *mass produced*, possibly at several sites. Information necessary to determine which set of antennas should be used at each segment of time could be determined with Earth sensors, or possibly from signals received by the receive antennas. Each antenna will be connected to a dedicated pre-amp and switching would presumably take place after the pre-amps so as not to degrade noise figure and dynamic range. As with Phase 3D, a common IF would be used to connect the various receiving and transmitting ports. The IF might include the LEILA circuit developed for Phase 3D. A block diagram of the proposed design is shown in Figure 3.

Mandating that inter-satellite linking be accomplished through ground stations rather than between the satellites themselves, eliminates a great deal of potential complexity from the spacecraft design. For example, none of the spacecraft's power need be used in linking and there is no requirement for additional antennas that must be kept pointed toward adjacent satellites.

As stated, the proposed spacecraft design would draw heavily on the Phase 3D heritage. It is proposed that it use the Phase 3D spaceframe design. If a launch can be obtained on a future Ariane 4 or 5, it would use the same launch interface, including the Specific Bearing Structure (SBS) which will be proven by the launch of Phase 3D. A liquid propellant motor, similar to, but smaller than, the 400 Newton unit on Phase 3D, will be required to get to final orbit from the GTO into which a launch vehicle would place the spacecraft. However, the process of getting to final orbit will be much less complex and require much less time and fuel than is the case with Phase 3D. An arc-jet, similar to that used on Phase 3D, might be used to effect stationkeeping.

Of course, some of the systems used in Phase 3D, but not needed for this application, would be eliminated. These include the reaction wheels and associated electronics, the magnetorquing rods, solar

panel deployment mechanism and the heat pipes.

Software to control this satellite would be much less complicated than that for Phase 3D. For one thing, the spacecraft would not change its mechanical characteristics as Phase 3D does when the solar panels are deployed. The only change would be as a result of fuel exhaustion. In addition, if the concept of firing the stationkeeping jet(s) at appropriate points in the satellite's rotation is valid, the proposed spacecraft would not have to be maneuvered for such firings as Phase 3D does.

Conclusion

This has been a brief outline of one possible approach to a follow-on to Phase 3D. Its ultimate intent, once enough satellites are built and launched would be to provide continuous real-time worldwide interconnection for the world's radio

amateurs. In the meantime, a single geosynchronous spacecraft would provide coverage of a single region of the Earth, presumably the region which built it. As additional spacecraft are built and launched, the entire world, except for the poles, would receive coverage. If a near-geosynchronous drifter is decided on the entire Earth can be provided with satellite service, but not all at the same time. Several such drifters would be needed provide worldwide full-time service.

This paper obviously does not represent a detailed design. It is intended merely to spur discussion and get a dialog going on follow-on projects and what form they might take.

References

Vekinis, Peter: "Participate in Picosats," *Proceedings of the AMSAT-NA 13th Space Symposium and AMSAT Annual Meeting 1995*, page 77. ■

Satellite Orbital Elements

Ray Hoad, WA5QGD

Satellite	AO-10*	AO-27	FO-20	FO-29	RS-10/11	RS-12/13	RS-15
Catalog Number	14129	22825	20480	24278	18129	21089	23439
Epoch Time	97054.50000000	97058.17601495	97057.94276107	97058.14910253	97058.15433328	97058.19221435	97057.82697469
Element Set	500	547	955	70	332	962	224
Inclination	25.8792	98.5531	99.0241	98.5567	82.927	82.9193	64.8184
RA of Node	163.0281	134.7935	40.3312	114.3199	320.074	0.2167	331.2995
Eccentricity	0.6052907	0.0007868	0.0539417	0.0352011	0.0011326	0.0027397	0.0151945
Arg of Perigee	93.3854	199.9133	267.0126	111.2601	159.6911	245.0252	153.0301
Mean Anomaly	313.1701	160.1748	86.9154	252.6501	200.4701	114.8055	207.8613
Mean Motion	2.05882272	14.27718898	12.83237534	13.52628832	13.72375032	13.74077255	11.27525561
Decay Rate	0.0000001	0.0000004	-0.00000026	-0.00000021	0.00000061	0.00000018	-0.00000039
Epoch Rev	10300	17837	33056	2624	48514	30405	8949
Satellite	EO-11	EO-14	AO-16	DO-17	WO-18	LO-19	UO-22
Catalog Number	14781	20437	20439	20440	20441	20442	21575
Epoch Time	97058.00085905	97058.17216405	97058.19062662	97058.18752772	97058.18291780	97058.15898758	97058.16624477
Element Set	960	266	67	49	69	67	776
Inclination	97.8219	98.5246	98.5436	98.5426	98.5479	98.548	98.3171
RA of Node	43.7113	142.1935	144.9144	145.6915	145.6065	146.189	122.52
Eccentricity	0.0012068	0.0010703	0.0011152	0.0011316	0.0011797	0.001205	0.0006822
Arg of Perigee	1.0656	167.8001	169.2119	167.877	169.0206	167.8412	219.6565
Mean Anomaly	359.0572	192.3443	190.9309	192.2693	191.1238	192.3066	140.4132
Mean Motion	14.69527285	14.29950738	14.29999491	14.30141691	14.30109962	14.3022313	14.37058134
Decay Rate	0.00000091	0.00000047	0.00000003	-0.00000013	0.00000017	0.0000002	-0.00000008
Epoch Rev	69507	37049	37051	37054	37054	37056	29468
Satellite	KO-23	KO-25	IO-26	POSAT	RS-16	MIR	Phase 3D 502 (est)
Catalog Number	22077	22828	22826	22829	24744	16609	99934
Epoch Time	97057.96149451	97058.14346892	97058.15288369	97058.16335802	97064.31869	97058.50291158	96.26025523
Element Set	663	537	544	554	7	82	3
Inclination	66.0864	98.5496	98.5552	98.5533	97.281	51.6504	60.0203
RA of Node	16.0256	135.0559	134.9936	135.1597	331.3169	277.2794	342.7876
Eccentricity	0.0013866	0.0009721	0.0008322	0.0009763	0.0009653	0.0011316	0.6752895
Arg of Perigee	240.5787	185.2606	203.066	186.1423	97.8509	120.0427	180.1221
Mean Anomaly	119.3841	174.8479	157.0152	173.9641	262.3741	240.1665	179.5089
Mean Motion	12.86301038	14.28168891	14.27827354	14.28152048	15.30859907	15.60579821	1.51063968
Decay Rate	-0.00000037	-0.00000002	-0.00000006	0.00000016	-0.00005782	-0.00000829	0.0002
Epoch Rev	21357	14650	17838	17842	19	62990	2

* Revised AO-10 elements - See article on page 7 of this issue.

SAREX Update: STS-83

Lou McFadin, W5DID (w5did@amsat.org)

STS-83, currently scheduled for launch on April 3, 1997 at 2:01 pm Eastern Standard Time (19:01 UTC) marks the 23rd flight for *Shuttle Amateur Radio Experiment* (SAREX). The planned mission duration is 15 days, 16 hours, and 29 minutes, making it one of the longest SAREX missions. The primary payload for the mission is *Microgravity Science Laboratory* (MSL).

The crew for the mission consists of Commander Jim Halsell KC5RNI, pilot Susan Still, Mission Specialists Janice Voss KC5BTK, Mike Gernhardt, and Don Thomas KC5FVF, and Payload Specialists Roger Crouch, and Greg Linteris. The alternate payload specialist is Paul Ronney.

The MSL builds upon experiments performed on previous Spacelab missions. MSL's experiments include combustion, proteins, plants, fluids, and containerless processing. For more information, visit the NASA Marshall Space Flight Center's World Wide Web page at <http://liftoff.msfc.nasa.gov/spacelab/msl/welcome.html>.

STS-83 is an extended duration orbiter flight. During extended duration flights, every watt of power is carefully allocated. The amount of power used by the shuttle's systems, experiments, and even the computers and lights for the crew cabin are carefully added. On this particular flight there are some very power-hungry experiments, primarily furnaces for the materials processing experiments, so the power budget is tight. So the *official* SAREX hardware, at least as far as the power consumption folks are concerned, is zero watts. About 10 to 15 battery packs will be carried, enough to complete all of the planned contacts plus plenty of power for random QSOs. Sixteen schools have been selected from the United States, Okinawa Japan, and The People's Republic of China for pre-scheduled contacts (Table 1). The hardware consists of the Motorola transceiver, window-mounted antenna, and assorted connecting cables and accessories. Technically SAREX is only planned to be used in the *voice-only* configuration.

However, there are a couple of loopholes which may permit additional SAREX activities. The energy folks are extremely conservative when calculating the amount of power required for any particular shuttle mission. So, just in case, the SAREX team is flying the additional hardware required for packet communications, the Heathkit TNC and serial cables for the standard shuttle notebook computers. *If* there is enough power the crew may be given permission to hook up the packet hardware. Please monitor

AMSAT News Service Bulletins or sarex@amsat.org for the latest news.

The standard SAREX Motorola radio has a limited number of frequency choices. The frequencies are programmed into e-proms on the current radio. SAREX on STS-83 will continue to use the standard SAREX frequencies (Table 2). In the future the *Amateur Radio on International Space Station* (ARISS) group will evaluate suitable frequencies as Amateur Radio activities transition from the shuttle to space station.

A more pressing concern is the number of SAREX missions per year. It is possible that STS-83 may be the only SAREX flight in 1997, although we're still trying to get on one additional flight. NASA has not lost interest in SAREX, but its priorities are

changing. The shuttle's flying less spacelab missions which are optimal for SAREX. Many of the shuttle flights are dedicated to the Shuttle-Mir program. That means there is less space available for secondary payloads.

SAREX had been planned for Shuttle-Mir missions. In some ways it was appealing, the same radio which was intended for shuttle-Mir communications could be used for SAREX just by programming in different frequencies. But experience has shown that the Shuttle-Mir flights are not good choices for SAREX.

Shuttle-Mir flights are challenging because they involve a ground-up rendezvous, matching the shuttle's orbit to *Mir* which is already in space. If one couples these complexities with the intense

crew timeline that is required of this supply and crew change-out mission, makes these flights not a good choice for SAREX. SAREX will continue to seek longer duration spacelab flights (like STS-83) to provide good opportunities for school group contacts and general QSO operations. SAREX operations on the shuttle will definitely continue to decrease as the shuttle is used less as a scientific investigation platform and more as a vehicle to shuttle equipment and crew to *Mir* and to construct the International Space Station (ISS). To bridge the gap, SAREX has worked closely with its international partners to allow astronauts on *Mir* to use the radio to talk to Radio Amateurs on the ground and with students in the United States. Currently, Jerry Linenger KC5HBR is making SAREX-Mir contacts to Radio Amateurs and has begun talking to school groups. Future articles in *The AMSAT Journal* will highlight the SAREX and ARISS team's progress in keeping human Amateur Radio in space alive and well on the shuttle, *Mir*, and ISS. In the meantime, we wish you all the best in communicating with the astronauts on STS-83! ■

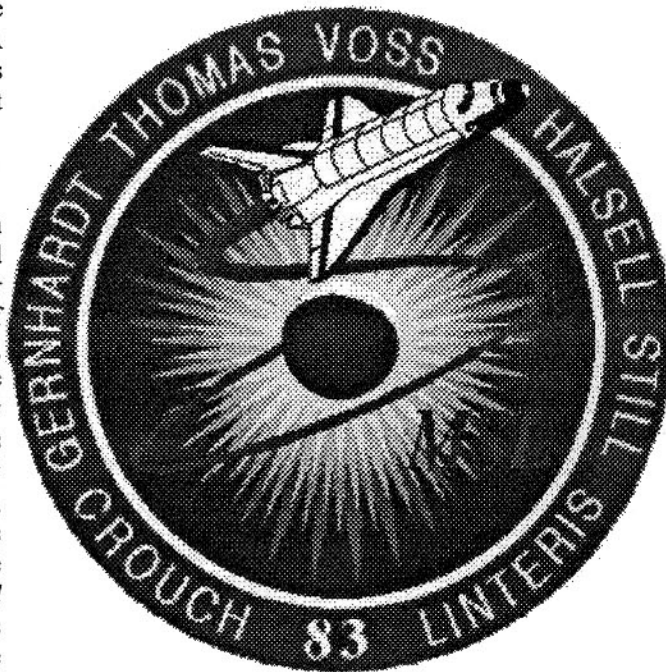


Table 1. STS-83 SAREX School Groups

- Mountain View Elementary School, Dewey, Arizona
- Center Street School, El Segundo, California
- Ione Junior High School, Jackson, California
- Crittenden Middle School, Mountain View, California
- Sonny Carter Elementary, Macon, Georgia
- Robert Burch Elementary, Tyrone, Georgia
- Edgewater High School, Orlando, Florida
- Lexington Traditional Magnet School, Lexington, Kentucky
- Beau Chene High School, Arnaudville, Louisiana
- Lawrence Intermediate School, Lawrenceville, New Jersey
- County College of Morris, Randolph, New Jersey
- Yeso Elementary School, Artesia, New Mexico
- Public School 9, New York, New York
- Alvin C. York Agricultural Institute, Jamestown, Tennessee
- J. Davis Middle School, San Antonio, Texas
- Troy Middle School, Troy, Texas
- Tsinghua, Beijing, China
- Lester Middle DoD Dependent School, Okinawa, Japan

Table 2. STS-83 SAREX Frequencies

The SAREX Working Group has designated the following frequencies during this mission.

- FM Voice Downlink: (Worldwide) 145.55 MHz
- FM Voice Uplink: 144.91, 144.93, 144.95, 144.97, and 144.99 MHz
- FM Voice Uplink: (Europe only) 144.70, 144.75, and 144.80 MHz
- FM Packet Downlink: 145.55 MHz
- FM Packet Uplink: 144.49 MHz

The crew will use separate receive and transmit frequencies. *Please* do not transmit on the shuttle's *downlink* frequency. The *downlink* is your receiving frequency. The *uplink* is your transmitting frequency. The crew will not favor either uplink frequency, so your ability to communicate with SAREX will be the *luck of the draw*. Transmit only when the shuttle is within range of your station, and when the shuttle's station is on-the-air.

Field Ops Update: AMSAT Area Coordinators Listing

Barry A. Baines, WD4ASW, wd4asw@amsat.org

It is time for our annual listing of AMSAT's Area Coordinators. Starting on page 29 of this issue you will find a listing of the 148 Area Coordinators (plus country representatives) who donate their time and energy to help represent AMSAT within their respective communities. These volunteers may give programs to local clubs, man AMSAT booths at local hamfests, serve as *Elmers* to folks getting started in Amateur Radio satellites, and establish AMSAT nets on local repeaters. Other activities that area coordinators have done include organizing local AMSAT gatherings and supporting AMSAT Field Day activities. They serve as *Ambassadors of AMSAT* in that they become the local contact for people needing information on the amateur satellite program.

The qualifications needed for being an area coordinator are simple: You must be a current member of AMSAT-NA, be willing to work with people, and have an interest in representing the organization as your time and interests permit. Recently, we established a prerequisite that all area coordinators must have Internet electronic mail capability so that all members of the Field Ops Team can easily be reached. E-mail provides an easy and cost effective avenue for distributing information, sharing ideas, and responding to requests for support. Given the variety of satellites in current use and the diversity of interests, area coordinators are not expected to know everything about the amateur satellite program. What is important is that each area coordinator be willing to find answers to questions and follow up with individuals looking for assistance. That is why we require electronic access, so that everyone can get information from other Area Coordinators and respond to queries in a timely manner.

We have certainly benefited from a great number of people who have stepped forward and volunteered to serve as Area Coordinators. Despite the turnover that occurs in volunteer organizations, we have about 20 more Coordinators listed this year than this time last year. However, 100 percent of those listed this year have e-mail capability (while only 66 percent did in last year's listing). More importantly, we now have area coordinators in Alaska, Idaho, North Dakota, and Rhode Island; states that were vacant in the previous distribution list. There are also overseas volunteers listed who utilize our field organization to help them develop interest in amateur satellites in their respective areas.

We continue to look for volunteers in South Dakota, West Virginia, and Wyoming as well as additional support in some of the larger states. If you are interested in serving as an Area Coordinator, please contact me via: e-mail, wd4asw@amsat.org; telephone, 904-398-5185 (home) or 904-359-1933 (work); 904-346-0192 (home facsimile). ■

Man-Portable Pacsat Operation

Chas Richard, W4HFZ (formerly KM4EM)

This is a collection of notes about my efforts to construct and operate a *Man-Portable Pacsat station*. Although the results to date have not been as successful as I had expected, I hope my experiences will be of benefit to others attempting similar operations. I am continuing in my efforts, and hope to shortly be able to report the details of a fully functional station capable of useful communications.

Having been bitten by the Pacsat bug, I successfully constructed a fully automatic digital satellite station, operating on both types of Pacsat birds (1200 baud BPSK downlink, LO-19 and AO-16, and 9600 baud FSK, UO-22, KO-23, KO-25). After being reassigned and selling the house, I was interested in maintaining access to the birds, and put together a portable station. I have attempted man-portable Pacsat operations from a variety of locations, including an apartment in Washington, DC, aboard ship from three U.S. locations, Key West, Florida, Ft. Lauderdale, Florida, and Groton, Connecticut, and from temporary quarters in Pearl Harbor, Hawaii. My equipment was designed so that it would fit in the luggage allowed by a commercial airliner.

Satellite Selection

My goal was Pacsat operations, so I did not consider *Mir* or other similar options. I looked at two choices: 1200 baud BPSK, and 9600 baud FSK. Both require a full duplex 2M/70 cm capability. The 1200 baud birds require a SSB receiver on 70 cm, FM on 2 meters for the uplink. The 9600 baud birds require a 9600 bd FM radio for both. I did not know of any really small, SSB capable dual band radios, the closest being the ICOM -820 and 821. I do not own one of these radios, and desired to use my existing

equipment, therefore, I did not pursue this option. However, they are good candidates for this type of station, and I am considering use of one for future operations. Other commercially available SSB capable radios (such as my FT-736) were considered too large to fit in the luggage. I would submit that the 1200 baud BPSK birds are the better choice for a station with limited capability, as they require less signal strength to hear, and have less uplink contention. However, the size of current commercially available SSB equipment and my budget ruled them out for my station. Homebrewing is an option I did not pursue because of time constraints, but is a way to overcome the limitations of commercial equipment.

The other possibility was the 9600 baud FSK birds. There are a number of small, dual band, 9600 baud capable mobile radios commercially available. I am currently using the Kenwood TM-733A. A caution with these radios; they will be advertised as full-duplex capable, a requirement for these operations. However, the radio may only be capable of voice full duplex, not digital. My TM-733 required modification to allow it to go full duplex via the packet port. Another problem is the tuning step size. The minimum step size of the TM-733A is 5 kHz, which does not allow for fine Doppler correction of the downlink signal. My experience shows the up to 2.5kHz tuning error often resulted in missed data. Another issue is the relatively poor transmit Bit Error Rate (BER) at 9600 baud on these radios. My FT-736 at 25 watts out easily outperforms the TM-733A at 50 with similar antennas, even in areas such as Hawaii, where there is little uplink contention. The May 1995 issue of *QST* contains a good discussion on this subject, worth reading prior to purchasing one for Pacsat use.¹ Dual Band HTs have been suggested, however, the advantage of mobile radios over HTs is greater power out, and a better receiver, in a not too much bigger package. My efforts centered on the use of the TM-733A.

Some specifics on the modifications required to use the TM-733A. From the factory, the radio will only provide data out from the band that it is set to transmit on. What is required is to pass UHF data while transmitting on VHF. This can be done by grounding pin 5 or 6 of the analog switch IC-404 or pin 24 of the CPU (IC-403). Alternatively, a switch could be added.

Grounding any of these pins ties receive data to the UHF side, independent of the transmit band select. It is still possible to use the radio for VHF terrestrial work, either by operating in the dual in-band mode, or by switching the jumper as discussed above. Also note that the control band will need to be set to UHF, to allow for Doppler correction during the pass, while keeping the transmit band selected to VHF. The manual for the radio discusses how to accomplish this. I would like to thank Bob Carlson, N0AOT, for providing the information on the required modifications.

I should note that I did not go out and purchase a TM-733A for Pacsat use. I had the radio in the shack for other reasons. Although the radio is a fine dual band voice and 1200baud AFSK radio, I would not recommend it for dedicated Pacsat use.

Antennas

I desired to use a dual band mobile vertical for my antenna, again for space and weight saving. I desired a groundplaneless



W4HFZ portable Pacsat set-up at Pearl Harbor, HI, August 1996.
(photo W4HFZ)

design, and wanted no more than 3 dB gain to preserve vertical coverage. I did some work with both the Diamond NR-770SA, and the NR-770RA. What I found with dual band antennas is that the patterns don't complement each other very well. The NR-770A does not require a ground plane on either band, but has two collinear 5/8ths elements on 70 cm, resulting in a too narrow vertical coverage. The 770SA is a 1/2 wavelength on 70 cm, just right, but requires a ground plane on 2 meters. If a groundplane is not used, the SWR on 2 meters is unacceptably high. If a groundplane is used the vertical coverage on 70 cm is too narrow, as the antenna acts like a collinear with the image of the upper element in the groundplane.

Another option is separate 2m and 70 cm antennas. I have done this, also. Performance was improved, but at the cost of carrying 2 antennas and feedlines. My latest effort was to attempt use of a Cushcraft A270-6S. This is a dual band, three element Yagi. With this arrangement, supporting and aiming the antenna was required. However, since I had to be present during the pass to correct for Doppler, it was little extra effort to go move the antenna once or twice during the pass. The advantages are the gain, and I have found some better intermod rejection in urban areas. The max dimension is about 4 ft, so it fits in the luggage.

Of all of these, the beam performed the best, as expected. I have only limited experience with circularly polarized omnidirectional antennas, such as the eggbeater and the quadifilar helix. While I would expect a circularly polarized antenna to outperform a linear one, in all my testing of omnidirectional antennas, nothing has outperformed a simple halfwave vertical for both uplink and downlink. Although I am continuing to pursue a rugged, small, CP antenna, and am following closely the good work being done in this area by several others hams, my recommendation for man-portable work is to use a half-wave vertical on both bands.

Power

This was the real hard part. I desired to be completely independent from commercial mains. I purchased a *DC Power Pack* from Innova. From full charge, it can support one, possibly two passes when powering the radio, TNC, preamp, and computer, with the computer being the largest load. This is at 10W output on the radio. I have been successful uplinking at 10W, but it is marginal. 30 or perhaps 50 watts is a lot more reliable, but costs battery lifetime. I have a larger 15 A-H pack that can support 4 or 5 passes at 50W on the uplink, but it is too large to carry in the luggage. Access to commercial mains helps significantly, however, to run the TM-733A at 50 watts out still requires 12-15 amps at 12 volts. A 12 amp power supply takes up a lot of room, and is heavy. I settled on the Innova battery with an accompanying 5 amp 12 volt AC supply, and charged the battery from the power supply between passes. This combination is slightly smaller and lighter than either the 15 A-H battery, or a 12 amp AC supply, and does permit some operations completely independent from AC mains.

Computer

Pacsat operations require a computer capable of running DOS. This will be the biggest power consumer (unless you are doing long uploads at high power), and a big chunk of the weight. Palmtops

such as the HP 200LX are probably the best choice. I already owned a small 486/25 laptop, which has worked fine.

Other Notes

I use the Kantronics KPC-9612 TNC. This small unit allows both 1200 baud and 9600 baud operation, allowing terrestrial packet between passes. Initially I had trouble getting the 9612 into KISS mode, required by the Pacsat groundstation software. A RESET command is required after changing to KISS mode (INTERFACE KISS), which was not obvious to me from the documentation. I used the PaKet 6 shareware packet program as a convenient method to issue the KISS OFF command when changing to terrestrial operation. Additionally, the MYDROP parameter has to be changed from 0/1 to 1/0, to allow the Pacsat software to talk to the 9600 baud port (PORT 2) when in KISS mode. There are several similar TNCs on the market to choose from. I also use a preamp. This is additional weight, extra power cables, etc., but the preamp has often made the difference between getting some data and getting nothing. My next planned improvement is a better preamp, with the capability of powering it off the feedline, or the use of a receive only antenna with an embedded Mini-Circuits MAR-6 or ERA-3 preamp.

I strongly recommend carefully adjusting all drive levels, deviation, etc. between components of the station to ensure it is fully optimized. I did not have time to do this, and as I was often right at the margin to decode data, I wished I had. Familiarity with Pacsat operations is helpful, and some test passes at home will help ensure data is not lost in the field based on equipment line up problems.

To date, my results have not been very encouraging. My best passes have been just over 150k, but the average is far lower, closer to 25k. Getting the antennas into the clear with limited feedline runs is a big problem. Although the station is not yet providing useable communications, it has been a lot of fun attempting to get it set up.

For comparison, after moving into the new house, I quickly set up the home station on omni antennas. Equipment used was an FT-736, SSB Electronics preamp, 1/2 wave vertical on 70 cm, and a separate 1/2 wave on two meters. Although I'm horizon blocked below about 20 degrees, the best 9600 baud passes were approaching 350k, with an average around 175k. Others have reported even better performance with similar equipment. I think these figures represent an achievable goal for a man-portable station. I have some improvements planned, getting ready for extended man portable operations next summer when I will be spending five months in the Mediterranean. I invite others who are working on portable and maritime mobile Pacsat stations to share their results, and hopefully you will see me in the queue this summer from my man portable station!

References

- 1) Bloom, Jon, KE3Z, "9600-Ready Radios: Ready or Not?" *QST*, May 1995. ■

Please allow 6-8 weeks delivery

flight SCOPE camera. Yoshiyuki installed and successfully powered up the SCOPE in the satellite on March 1st.

Back in Germany, Konrad Mueller, DG7FDQ, AMSAT-DL's Structural Specialist and the person responsible for fabrication of the flight momentum wheels for the spacecraft, was putting the finishing touches on the flight wheels prior to their imminent shipment to Florida. Just prior to their departure from Germany, Werner and Peter received a high quality, fully populated circuit-board for control of the momentum wheels from Chuck Green.

It is a very busy time for the project. However, so far, integration and testing are progressing on schedule for Phase 3D's July launch on Ariane 502.

AMSAT-NA 15th Annual Meeting and Space Symposium

The 15th Annual Meeting & Space Symposium will be held October 17-19 1997 at the Airport Delta Hotel, Toronto Canada.

The tentative agenda includes:

- A full program of papers on Phase 3D and other new satellites.
- Annual Meeting.
- Saturday evening banquet with Guest Speaker.
- AMSAT-NA Board meeting.
- AMSAT Coordinators meeting and breakfast.
- IARU Satellite symposium.

Help make the 15th AMSAT-NA Space Symposium the most successful. Celebrate the launch of Phase 3D! Offer your paper for inclusion in this important event. Topics for all amateur satellite disciplines are sought.

- Author and title requested by March 1 1997.
- A short abstract composed by June 1, 1997.
- Final Drafts are requested by August 1, 1997.

Even if you cannot attend consider a paper for publication! Send your input to: Wayne Chandler, VE3WHC, Box 6, Carlisle, Ontario, Canada, L0R 1H0 or ve3whc@amsat.org.

Call for Papers for the 12th AMSAT-UK Colloquium

The 12th AMSAT-UK Colloquium will be held at Surrey University, Guildford, Surrey, U.K., from 25-27 July 1997. Since IARU will be at the AMSAT-NA symposium, this year's event will comprise three days of technical matters only; there will be no political subjects. AMSAT-UK invites authors to submit papers, about Amateur Radio space and associated activities, for this event; AMSAT-UK normally prefers authors to present the papers themselves rather than having someone else read them in the authors' absence.

Abstracts of Papers for presentation should be submitted as soon as possible; the date for full submissions will be announced in the future bulletin. It is likely that the final date will be about one month prior to the event in order that the *Proceedings* document be available to participants.

Submissions should be sent *only* to G3RWL, via the following routes:

- Internet e-mail: g3rwl@amsat.org.
- Packet Radio: G3RWL @ GB7HSN.#32.GBR.EU.
- Terrestrial mail: R. W. L. Limebear G3RWL, 60 Willow Road, Enfield EN1 3NQ, United Kingdom.

AMSAT-UK also invites anyone with requests for Program Topics to submit them as soon as possible to G3RWL as above. Invitations for papers on specific subjects will be included in a future bulletin. (via AMSAT News Service)

RS-16 in Orbit!

Shortly before press time, a flurry of reports were posted on amsat-bb about the March 4, 1997 launch of RS-16 from the Svobodnyi Cosmodrome in Amur Oblast, Russia. Launched by a modified SS-25 ballistic missile, RS-16 is presently in a 508 x 472 km orbit at a 97.8° inclination. Via an e-mail message to Eric Rosenberg WD3Q, Vladimir Agapov reports that RS-16 is an Amateur Radio payload that is part of Zeya and not a secondary payload satellite. Zeya is equipped with one 29.4 MHz antenna, four 435 MHz antennas and one (possibly two) 145.800 +/- 0.2 MHz antenna. The total weight of the Amateur Radio payload is 14 kg (from 87 kg of total satellite weight). Zeya is also equipped also with 20 laser-reflectors for tracking purposes along with GLONASS and GPS receivers. Apparently Zeya's bus is based on an old small military communication satellite. Also, Andy, RK3KPK, passed along this preliminary RS-16 frequency information to B.J. Arts, WT0N, AMSAT New Service:

- Uplink: 145.915 - 145.948 MHz

- Downlink: 29.415 - 29.448 MHz
- Beacons: 29.408, 29.451 MHz
- Power 29 MHz Down: 1.2 W / 4 W
- Beacon 1: 435.504 MHz
- Beacon 2: 435.548 MHz
- Power 435 MHz Beacons: 1.6 W

As of press time, RS-16's transponders have not been turned on. However, there have been many world-wide 29.408 MHz CW telemetry beacon reports. Also a Keplerian element set for RS-16 is provided in the Orbital Element section of this issue (page 17).

OSCAR SKN Best Fist Winners

Ray Soifer, W2RS reports that activity during AMSAT-NA's 25th Annual Straight Key Night on OSCAR was good, despite the loss of AO-13. In addition, RS-10 and RS-12 were especially active, with some SKN stations logged on AO-10, RS-15 and FO-20 as well.

For the second year in a row, our Grand Prize winner is Rusty Hack, NM1K. Last year, Rusty received four separate nominations; this year, he got six! Other Best Fist winners, each for the first time, include Bill Collins, K8NQC; Franz Schmiderer, OE2SNL; Dave Stephenson, VE3PYG; and Howard Newton, W2FB. Congratulations to one and all. See you next year, hopefully on Phase 3D!

Balloon Information on AMSAT WWW

During the 1996 AMSAT Annual Meeting & Space Symposium, the AMSAT-NA Board of Directors asked Doug Howard KG5OA to be a *liaison* for high altitude balloon projects. It was felt that there were many similarities between these two facets of amateur radio which might be better approached in a coordinated fashion. The AMSAT-NA Board of Directors voiced a specific interest in the similar goals of educational opportunities, especially as it applies to young people.

As a first step, a World Wide Web page has been created to serve as an information resource for AMSAT members who are interested in high altitude ballooning, as well as for balloon projects themselves. A link has been established from the main AMSAT web page at the following URL: <http://www.amsat.org/amsat/AmsatHome.html>

We hope you enjoy this new information resource. KG5OA would like to thank Paul Williamson KB5MU, for all of his coordination and help with this new web page. (via amsat-bb)

Kenwood Amateur Radio Self Study Package Available

Kenwood's new self study package, *Make a Personal Connection*, for the Technician FCC license is available. Included in the package is EZ-PASS, a PC Windows training program that makes learning fun and easy. An Amateur Radio license study manual supports the software with information on operating rules and electronic theory. An Amateur Radio Primer, *How to Get On the Air Guide*, and Amateur Radio frequency charts are included to help one prepare to quickly pass their test and get on the air. A Windows 95 and DOS version of *Make a Personal Connection* will be available at local Amateur Radio dealers. ■

NOVA for DOS, Windows or new Windows 95: \$49.95. WinTrak Pro: \$69.95. SASI Sat Tracker: \$279.95. Freq. Mgr. (radio auto-tune for Doppler shift): \$65.95. SB-32 Mode S 2'X3' Parabolic Dish antenna for 2.4 GHz: \$55.95. Yaesu G-5400B Az/EI rotor: \$526.95. Shipping extra on all. Dealer for all M2, Eggbeater and KLM antennas: Call for prices. OSCAR Satellite Report Newsletter: \$35 USA. Elsewhere higher. Special 8' Fiberglass boom, 1-1/2 inches solid: \$79.95. HF antennas and rotors, too! Call/write/email. Check our Web page.

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The UK End of the Ultra-QRP Satellite QSO. Pat Gowen, G3IOR working W2RS from the highest hill (125' ASL) in the Norwich area, 7 Dec 1996.

Hand(Held)s Across the Sea

Pat Gowen, G3IOR and Ray Soifer, W2RS

Have you ever looked at your handheld transceiver and wished it could work real, transoceanic DX instead of just the local repeater?

Hearing of Ray's RS-10/11 QSOs with his *micro-station* (*The AMSAT Journal*, Nov-Dec 1996) got Pat thinking: it's one thing to work nearby stations on overhead passes, but would it be possible for two handheld transceivers to work each other across the Atlantic? And, if so, wouldn't that be a perfect demonstration of how easy it is to access the *Easy-sats*?

In November 1996, during one of his frequent visits to London (about 200 km from Pat's QTH in Norwich), Ray made several contacts through RS-10/11 using the *micro-station*. To test things out, we set up a schedule for 23 November 1996, the last morning of his stay.

To avoid obstructions, Ray set up operation from a bench in St. James's Park, London (fortunately, it was a cold morning with few people about), holding the Sony ICF SW-100E receiver on his lap and waving the 2m handheld around to produce the best signal into RS-10/11. Pat used a similar set-up with an ancient TR-2400 for the uplink, except that he used an ICOM IC-720A powered by a 12 volt battery to copy the transponder downlink. Both stations made a perfect contact with Pat receiving an RST 549 and Ray receiving a 534 report (keying an FM rig doesn't produce the cleanest of CW notes).

To our knowledge, this was the first time that two similar handheld stations had worked each other via RS-10/11. Soon after returning home, Ray made a second two-way handheld QSO with Stan Brigham, W3TFA.

Only one thing remained: a QSO across the pond. Our home stations are separated by about 5600 km, which severely limits the

time during which RS-10/11 would be within mutual range of both, especially with so little power and simple whip antennas for transmitting and receiving.

Two more schedules were made. This time, Pat went portable on the highest nearby hill using his handheld and receiving with the IC-720A and a 29 MHz mobile whip antenna on his car. Pat copied Ray and gave him an RST of 534, but with the little Sony receiver, Ray could hear neither Pat nor his own downlink on the first mutual RS-10/11 window.

The second attempt on Saturday, 7 December 1996, was successful both ways. Contact was made between 1047 and 1050 UTC. Pat gave Ray an RST of 524, while Ray gave Pat a 449 report. Ray was using an effective radiated power (EIRP) of about two watts, while Pat's was only about one watt. At the time of completion, RS-10/11 was about 10 degrees above Ray's northeastern horizon while only about 2 degrees above the horizon to Pat's northwest.

The success of this experiment shows the excellent sensitivity of RS-10/11 when it is not overloaded by many stations running higher power. It also proves that it doesn't take high power or expensive equipment to make successful satellite contacts. Sometimes it just takes a clear frequency and a little creativity.

By an interesting coincidence, this ultra-QRP satellite QSO across the Atlantic was made 75 years to the day after Paul Godley's hearing the first transatlantic amateur signal, on 270 meters at Ardrossan Moor. Exactly twenty years before that, on 7 December 1901, Marconi was hard at work building the Newfoundland receiving station with which, five days later, he was to copy the letter "S" sent from Poldhu, Cornwall. We hope they would have been pleased. ■

Omni-Directional, VHF Transmitting Antennas for use with Analog LEO Satellites

Anthony Monteiro, AA2TX (aa2tx@amsat.org)

By using an omni-directional antenna, you can avoid the high cost and considerable complexity of tracking satellites with azimuth/elevation rotators. But aside from being omni-directional, what other aspects of the antenna are important? This article investigates the major factors that determine antenna performance and offers a set of guidelines for desired characteristics. While the title of this article may at first seem overly narrow, the discussion of the issues will clarify why the specific antenna application is important. Current LEO satellites with VHF up-links and analog transponders include RS-10, RS-15, FO-20, and FO-29.

Background

I used a 2 meter vertical ground-plane for my initial attempts at accessing RS-10. Although I was able to make contacts with this antenna, its performance left much to be desired. At 25 watts PEP, I could make SSB contacts only from about 20 degrees elevation or higher. On CW, I was able to make contacts down to about 10 degrees but with significant fading problems.

When RS-15 was launched, I tried, but was unable to make any contacts using this antenna while running 25 watts CW. I could always copy the beacon Q5 but I generally could not hear my own down-link.

What Makes a Good Antenna?

Rather than just trying a few other antennas, I decided to identify the properties of the satellite radio link that are affected by the antenna and then specify an idealized *reference* antenna to use as a guideline for evaluating and selecting a new antenna. The major properties that I have addressed are the *Path Loss*, *Faraday Rotation*, *Antenna Polarization*, *Satellite Visibility*, and *Communications Range*.

Path Loss

When we use practical antennas to send and receive, some, if not most, of our signal will escape out into space rather than be picked up at the satellite receiving antenna. Physically *smaller* antennas allow more of the signal to escape than *larger* antennas. For example, if we scale down a VHF antenna to make a UHF antenna, its gain would be the same but the signal power that the UHF version captures will be less. Similarly, as we move the antennas farther and farther apart, more signal escapes.

Path Loss is a convenient mathematical way to express this concept. Although this is not a *real* power loss, the effect on the communications path is the same. The path loss can be calculated as follows:

$$\text{Path Loss} = 20 \text{ LOG} (4 * \pi * \text{Distance} / \text{Wavelength})$$

As we can see, the path loss is a function of the signal wavelength and distance of the satellite to our location. This distance is called the *range*. With a little trigonometry, we can express the satellite range as a function of its elevation angle from our location. We can then calculate how the path loss changes as the satellite travels across the sky.

The following chart shows the path loss as a function of elevation angle for several LEO satellites (both analog and digital.) Of the currently operational satellites, RS-15 has the highest orbit at 2164 km and AO-16 has the lowest at 800 km. Note that this chart is based on simplifications of a spherical earth as well as circular geocentric orbits. Satellite apogee heights were used as the orbit heights.

As shown in Figure 1, the path loss varies considerably over the range of elevation angles. This means that the up-link power needed for a constant signal level at the satellite varies throughout the satellite pass. More power is needed when the satellite is at the horizon than when it is overhead.

Although the curves are different for each satellite, the *shape* of the curves, for the current analog satellites, differ by only about 2 dB maximum. RS-15's curve shows the smallest change, 8dB from 0 to 90 degrees, while RS-10's shows the largest change, about 10 dB.

Faraday Rotation

Faraday rotation is a change in the polarization of an electromagnetic wave as it travels through the Earth's ionosphere. The amount of change is a function of a number of factors including the distance traveled and the wavelength. A model for calculating the Faraday rotation is developed by Kraus [2]. For an overhead pass, a 146 MHz satellite link will typically experience about 6 complete rotations [1]. This means that if we transmit using a vertically polarized antenna, the actual polarization seen at the satellite will vary from vertical to horizontal and back about 12 times during the pass.

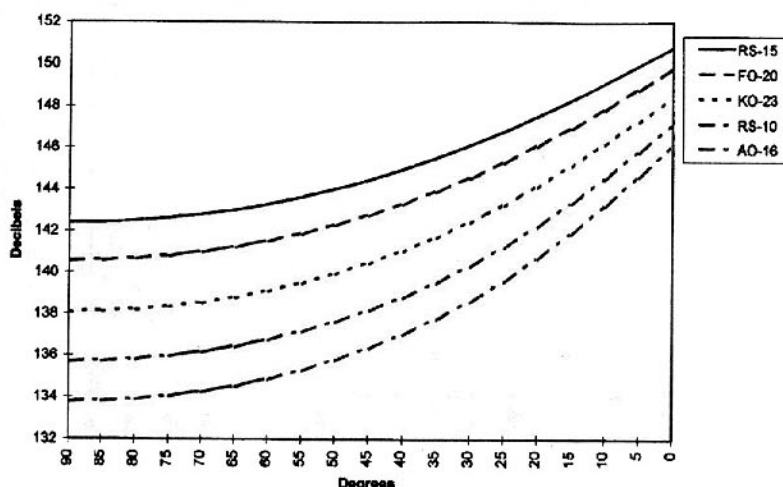


Figure 1. Path loss versus elevation angle.

Antenna Polarization

When a linearly polarized signal is received by a linearly polarized antenna but the polarizations do not match, we experience a *polarization mismatch loss*. The amount of loss depends on the angle between the antenna polarization and the signal polarization. The minimum loss of 0 dB will occur when the angle is 0 degrees and the maximum loss will occur when the angle is 90 degrees. The relationship between the angle and the loss is approximately as follows:

$$\text{Loss (dB)} = -20 \text{ Log} (\cosine(\text{angle}))$$

For real antennas, the maximum loss is around 30 dB. This relationship is shown in the Figure 2.

Due to the Faraday rotation, the angle between the antenna and the signal will change throughout the satellite pass. At any given moment when we wish to contact another station, we generally will not know this angle. From a practical standpoint, we can consider the angle to be random.

Although we cannot predict the loss at any given time, we can determine the loss we should *expect* by finding the average loss. When we calculate this we get 6 dB. This means that if we use a linearly polarized transmit antenna to communicate with a satellite that has a linearly polarized receive antenna, on average we will lose 6 dB due to mismatched polarization. Since this loss is not constant, we will experience QSB as the angle changes, sometimes the loss will be close to 0 dB and other times it will be up to around 30 dB.

An alternative is circular polarization. When a circularly polarized wave is received with a linearly polarized antenna the received amplitude does not change. If we use a circularly polarized transmitting antenna to transmit to a linearly polarized receive antenna, we incur a constant 3 dB loss due to the polarization mismatch but we will not experience fading. This is 3 dB less loss, on average, than if we use linear polarization. So, for the same antenna gain and transmitter power, a circularly polarized transmit antenna will produce a stronger *average* up-link signal than a linearly polarized transmit antenna when the receive antenna is linearly polarized.

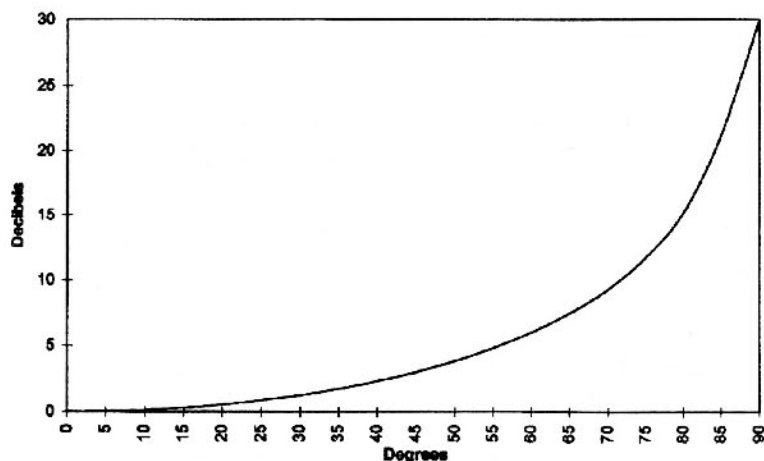


Figure 2. Polarization loss versus angle.

When the satellite's receive antenna is circularly polarized, such as with FO-20 or FO-29, we can use either circular or linear polarization at our transmit antenna without incurring substantial fading from the Faraday rotation. If we use linear polarization however, we will incur a constant 3dB loss from polarization mismatch.

If we use circular polarization, we avoid this loss, assuming that we use the proper polarization sense. Should the satellite be tumbling or otherwise mis-oriented with respect to the ground station, its antenna's polarization sense may become elliptical or even linear rather than truly circular. In this case we will incur a mismatch loss but we still do better than with the linearly polarized antenna since its mismatch loss will also increase.

Thus, at frequencies that are subject to Faraday rotation and for satellites having either linearly or circularly polarized receive antennas, a circularly polarized ground station antenna will produce a stronger average uplink signal than will a linearly polarized one when they both have the same gain.

Satellite Visibility

The percentage of operating time when a satellite is at high elevation angles is small relative to the time when it is at low elevation angles. This means that most of our operating time (i.e. when the satellite is visible) will be at relatively low elevation angles. Figure 3 provides a summary of the percentages of operating time available for several representative satellites at various elevation angles for 42 degrees latitude.

As shown in the table, all current satellites have over 75 percent of their operating time below 30 degrees. None of the satellites are visible for more than 4 percent of the time above 60 degrees.

Communications Range

The best DX opportunities occur not when the satellite is at high angles but when it is near the horizon. In fact the maximum communications distance is up to two times as far at low elevation angles as it is when the satellite is overhead. Additionally, we can sometimes take advantage of ionospheric propagation to further increase our communications distance at low elevation angles. Thus for best DX, we want to optimize for the lower rather than higher elevation angles.

Antenna Characteristics

Now that we have discussed the issues, we can identify the characteristics of our theoretical reference antenna. *Note that there is no one optimal antenna.* The discussion and these specifications should be considered a guideline. Other factors may also play a part such as cost, size, and commercial availability.

Elevation Gain Pattern

Since the path loss is highest at the horizon and lowest overhead, our antenna's pattern should have the most gain at the horizon and should decrease as the elevation angle increases. By selecting a gain pattern that is opposite the path

loss curve, we can virtually eliminate the signal variation due to changing path loss. We also make best use of our available transmitter power since we will be radiating the most power where we need it.

Since RS-15 has the highest altitude, I selected its path loss curve as pattern to use for the reference. This means that the up-link signal would be relatively constant when using RS-15 but will increase slightly on other satellites as they travel from the horizon to overhead. This increase is only about 2 dB on RS-10 and is less on the other analog satellites. If we selected one of the lower orbit satellite curves instead, the RS-15 up-link would actually get slightly *weaker* as the satellite gets closer.

Polarization

Circular polarization virtually eliminates fading due to Faraday rotation and in all cases provides an average up-link signal that is 3 dB stronger than a linearly polarized transmitting antenna with the same gain. Therefore we would expect better results from a circularly polarized antenna, even if it has up to 3 dB less gain.

All current LEO satellites with VHF up-links use either right-hand, circular polarization or linear polarization. Therefore our ideal reference antenna would have right-hand, circular polarization.

Beamwidth

Antennas do not create any power, they achieve gain by narrowing the width of the radiation pattern. For an omni-directional antenna, we can only increase the gain by decreasing the width of the elevation pattern. Since most of our operating time and our best DX opportunities are at low elevation angles, we can achieve higher gain at these lower angles by reducing the gain at the higher angles. By optimizing for the range from the horizon to 30 degrees we can get higher gain than would be possible with a wider range and yet we still maintain at least 75 percent operating time. This selection is of course somewhat arbitrary and represents an optimization for best DX.

Reference Antenna Specifications

To summarize, our theoretical reference antenna specifications are as follows:

- Elevation gain pattern that is inverse of the RS-15 path loss curve.
- Right-hand circularly polarized.
- Optimize gain for elevation angles between 0 to 30 degrees.

Comparisons

We can use our ideal antenna specification as a guide for evaluating real antennas. Using EZNEC and Microsoft Excel, I modeled and analyzed the most popular omni-directional antenna types including the quarter-wave

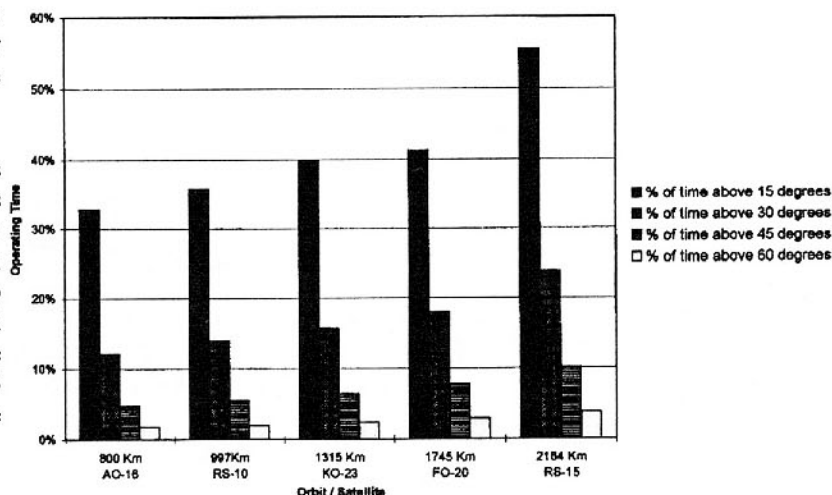


Figure 3. Satellite visibility.

ground-plane, the j-pole, the turnstile, and the Lindenblad. The ground-plane and j-pole are vertically polarized. The turnstile produces horizontal polarization up to about 60 degrees elevation and circular polarization from 60 to 90 degrees. The Lindenblad produces circular polarization up to about 70 degrees. The Quadrifilar antenna was not included since it produces very little radiation below 30 degrees.

All antennas were modeled as if they were on a 40 foot mast over a very good ground. It is important to remember that the gain of an actual antenna is typically not quite as high as the model predicts. The EZNEC analysis shows fairly sharp radiation lobes. In the real world, the antenna will likely be affected by reflections from nearby objects and varying ground conditions. The lobes will be less pronounced and maximum gain will be less. Regardless of these effects, EZNEC provides a very good basis for *comparing* antennas which is how we are using it here.

The gain patterns of the antennas from 0 to 30 degrees are shown in Figure 4 along with a reference curve showing the desired shape of the pattern. This chart shows the gain when the satellite's receiving antenna is circularly polarized like FO-20's. If the satellite's receiving antenna is linearly polarized, like RS-10's, we must subtract an additional 3 dB from each of the antenna curves to get the *average* effective gain.

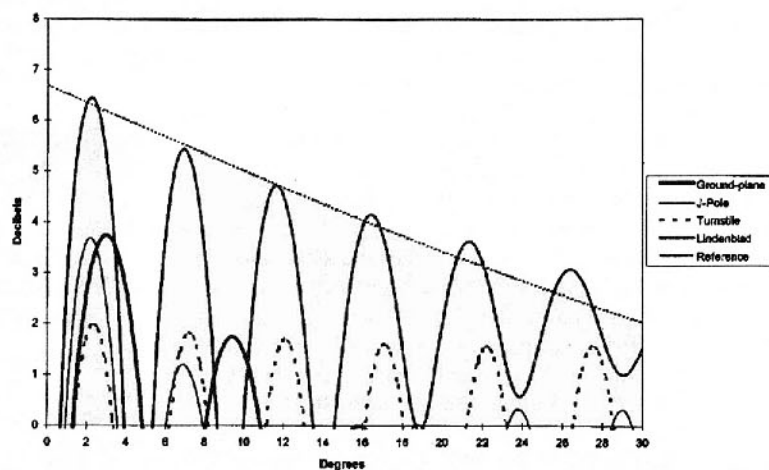


Figure 4. Gain versus elevation angle.

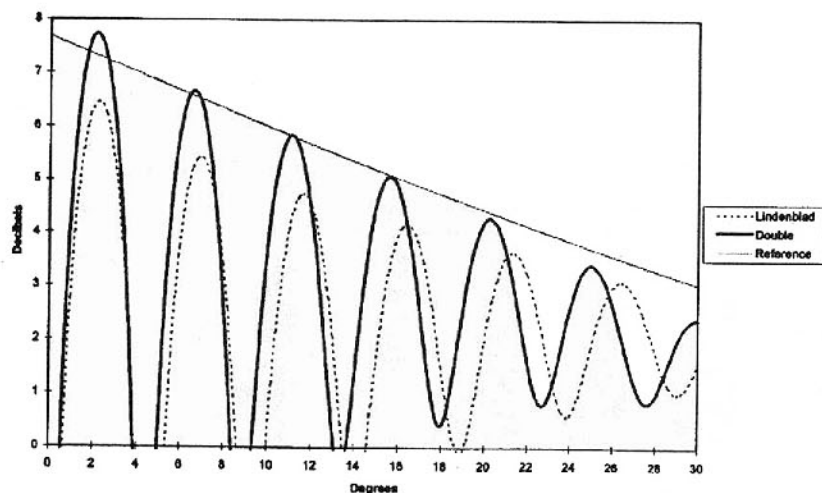


Figure 5. Gain versus elevation angle.

As we can see from the chart, the $\frac{1}{4}$ wave ground plane and j-pole antennas have their peak gains at around 2-3 degrees. The gain of these antennas falls off rather quickly and is less than 0 dB over most of the range up to 30 degrees. The vertically polarized radiation from these antennas will result in uplink fading on RS-10 and RS-15. Overall, the performance of these antennas is rather poor. These antennas should be considered a compromise at best. In their favor, they are widely available commercially and most hams probably already own one for 2 meter FM.

Above 5 degrees or so, the turnstile provides higher gain than the vertical antennas but its gain does not taper off as much as we

would like. This means that the uplink signal strength at the satellite will be increasing as the satellite get closer, and we are wasting some of our transmitting power. The horizontally-polarized radiation from this antenna will result in uplink fading on RS-10 and RS-15. Overall, the performance of the turnstile is better than verticals but it is far from ideal. On the plus side, a version of the turnstile known as the "Eggbeater" is available commercially.

The Lindenblad has up to 3-5 dB more gain than any of the other antennas and its gain curve is the best match to the reference gain curve. This means that the up-link power at the satellite will be less variable than with the other antennas throughout the pass. Since the Lindenblad is circularly polarized, it will not be subject to polarization-rotation fading when used on RS-10 and RS-15. Of the most commonly used omni-directional antennas, the Lindenblad has *by far* the best performance. The major negative is that it is not available commercially for 146 MHz so you have to build your own.

An Improved Lindenblad

Although the Lindenblad has the best performance of the most common omni-directional antennas, it can still be improved upon. Its gain should drop off faster as the elevation angle increases and further investigation shows that it has substantial radiation above 30 degrees. This means that we are wasting some of our transmitting power.

We can improve on the basic Lindenblad by using a phased array of them. I modeled two-element, vertically stacked, phased-arrays at various spacing. At $\frac{3}{8}$ wavelength spacing, we obtain a good compromise between maximum gain and 30 degree elevation coverage. The gain curve is plotted in Figure 5.

This *Double Lindenblad* produces more gain than the Lindenblad at angles less than 30 degrees and it follows the reference curve closer resulting in better use of our available transmitting power.

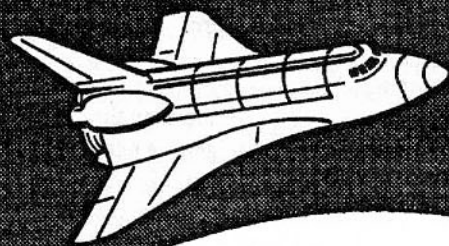
Experiment

I designed and constructed a prototype of the *Double Lindenblad* described above. I mounted it on my roof at a height of approximately 40 feet. The very first time I called CQ on RS-15, I was answered by Jean Claude Richard, F9YR (France) who gave me a 459 RST. This was using the same 25 watt CW transmitter that I had used before with no success.

For reference, I conducted an experiment on FO-20 with the satellite at 20 degrees elevation and at night when there were no other

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users. A 2.5 watt CW transmit level produced an S5 down-link as shown on my radio's (Kenwood) S-meter against a background noise level of S3. Thus, I found that I could obtain a Q5, CW signal with only 2.5 watts of transmitting power.

I have been using this prototype antenna for about a year to access RS-10, RS-15, FO-20, and FO-29. Its performance has been a dramatic improvement over my old ground-plane.

Summary

This article has discussed the major factors that affect the performance of an omni-directional, VHF, up-link antenna for LEO satellites with analog transponders. By using these factors we are able to describe a reference antenna specification which allowed us to evaluate the performance of commonly used antennas as well as guide us in developing a prototype antenna with better performance.

The reference antenna specifications would probably be different for other satellite applications. For receiving applications, high-gain at the horizon means substantial noise pickup from the earth so the received signal to noise ratio may not increase much with increasing gain. At microwave frequencies, there is no appreciable Faraday rotation. For WEFAX or digital store-and-forward satellite applications, optimizing for the few high-angle passes each day may be more desirable than optimizing for best low-angle DX.

I welcome all comments and suggestions. If anyone would like to duplicate my prototype Double Lindenblad antenna, contact me via email at aa2tx@amsat.org or regular mail at my callbook address.

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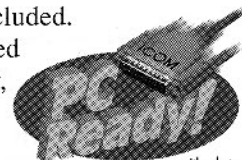
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